Fil
621
.P51
1st set

SCIENTIFIC LIBRARY

VOL. X, SEC. A, NO. 4 JULY, 1915

THE PHILIPPINE JOURNAL OF SCIENCE

ALVIN J. COX, M. A., PH. D.
GENERAL EDITOR

SECTION A

CHEMICAL AND GEOLOGICAL SCIENCES AND THE INDUSTRIES

EDITED WITH THE COÖPERATION OF

W. E. PRATT, A. M.; R. R. WILLIAMS, M. S.; D. S. PRATT, PH. D.
J. R. WRIGHT, PH. D.; H. C. BRILL, PH. D.; G. W. HEISE, M. S.
R. C. McGREGOR, A. B.; H. E. KUPFER, PH. B.

BUREAU OF SCIENCE
MANILA

MANILA
BUREAU OF PRINTING
1915

PUBLICATIONS FOR SALE BY THE BUREAU OF SCIENCE, MANILA, PHILIPPINE ISLANDS

ETHNOLOGY

A VOCABULARY OF THE IGOROT LANGUAGE AS SPOKEN BY THE BONTOC IGOROTS

By WALTER CLAYTON CLAPP

Order No. 408. Paper, 89 pages, $0.75, postpaid.

The vocabulary is given in Igorot-English and English-Igorot.

THE NABALOI DIALECT

By OTTO SCHEERER

and

THE BATAKS OF PALAWAN

By EDWARD Y. MILLER

Order No. 403. Paper, $0.25; half morocco, $0.75; postpaid.

The Nabaloi Dialect (65 pages, 29 plates) and the Bataks of Palawan (7 pages, 6 plates) are bound under one cover.

THE BATAN DIALECT AS A MEMBER OF THE PHILIPPINE GROUP OF LANGUAGES

By OTTO SCHEERER

and

"F" AND "V" IN PHILIPPINE LANGUAGES

By CARLOS EVERETT CONANT

Order No. 407.

These two papers are issued under one cover, 141 pages, paper, $0.80, postpaid.

THE SUBANUNS OF SINDANGAN BAY

By EMERSON B. CHRISTIE

Order No. 410. Paper, 121 pages, 1 map, 29 plates, $1.25, postpaid.

Sindangan Bay is situated on the northern coast of Zamboanga Peninsula. The Subanuns of this region were studied by Mr. Christie during two periods of five and six weeks, respectively.

The 29 plates illustrate the Subanuns at work and at play; their industries, houses, altars, and implements; and the people themselves.

THE HISTORY OF SULU

By NAJEEB M. SALEEBY

Order No. 406. Paper, 275 pages, 4 maps, 2 diagrams, $0.75, postpaid.

In the preparation of his manuscript for The History of Sulu, Doctor Saleeby spent much time and effort in gaining access to documents in the possession of the Sultan of Sulu. This book is a history of the Moros in the Philippines from the earliest times to the American occupation.

ETHNOLOGY—Continued

STUDIES IN MORO HISTORY, LAW, AND RELIGION

By NAJEEB M. SALEEBY

Order No. 405. Paper, 107 pages, 16 plates, 5 diagrams, $0.25; half morocco, $0.75; postpaid.

This volume deals with the earliest written records of the Moros in Mindanao. The names of the rulers of Magindanao are recorded in five folding diagrams.

NEGRITOS OF ZAMBALES

By WILLIAM ALLAN REED

Order No. 402. Paper, 83 pages, 62 plates, $0.25; half morocco, $0.75; postpaid.

Plates from photographs, many of which were taken for this publication, show ornaments, houses, men making fire with bamboo, bows and arrows, dances, and various types of the people themselves.

INDUSTRIES

PHILIPPINE HATS

By C. B. ROBINSON

Order No. 415. Paper, 66 pages, 8 plates, $0.50 postpaid.

This paper is a concise record of the history and present condition of hat making in the Philippine Islands.

THE SUGAR INDUSTRY IN THE ISLAND OF NEGROS

By HERBERT S. WALKER

Order No. 412. Paper, 145 pages, 10 plates, 1 map, $1.25, postpaid.

Considered from the viewpoint of practical utility, Mr. Walker's Sugar Industry in the Island of Negros is one of the most important papers published by the Bureau of Science. This volume is a real contribution to the subject; it is not a mere compilation, for the author was in the field and understands the conditions of which he writes.

A MANUAL OF PHILIPPINE SILK CULTURE

By CHARLES S. BANKS

Order No. 413. Paper, 53 pages, 20 plates, $0.75, postpaid.

In A Manual of Philippine Silk Culture are presented the results of several years' actual work with silk-producing larvæ together with a description of the new Philippine race.

THE PHILIPPINE
JOURNAL OF SCIENCE
A. CHEMICAL AND GEOLOGICAL SCIENCES
AND THE INDUSTRIES

VOL. X JULY, 1915 No. 4

THE LOCATION OF ARTESIAN WELLS IN THE PHILIPPINE ISLANDS FROM A GEOLOGIC VIEWPOINT[1]

By WALLACE E. PRATT
(From the Division of Mines, Bureau of Science, Manila, P. I.)

It will be assumed that the reader is conversant with the principles governing the phenomena of artesian wells, and in the following discussion no attempt will be made to consider the numerous factors which control the subsurface accumulation of water under hydrostatic conditions.

The conditions under which water-bearing rocks, like intercalated sandstones and shales, were laid down in the Philippines, where the distribution of land masses is irregular and the interruption of sedimentary processes by vulcanism was frequent, were so variable that no single bed nor any series of beds extends uniformly over great distances. Thus it is not possible here, as it is, for instance, in Australia, to map closely the outcrop of the " intake beds" nor to calculate the depths at which such beds will be encountered over large areas.

It is probable that very often wells will be drilled at towns which need most urgently a supply of potable water, irrespective of the chances of obtaining water. Frequently there will be little choice between different possible locations in a small town, and it may be found expedient to locate the well on the plaza or at some other central point without taking into consideration any other controlling factors. However, where towns are so situated as to include within their area parts of different geologic formations, there may be opportunity to exercise some discretion in choosing a drilling site.

---

[1] Received for publication May 28, 1915.

A large proportion of the flowing wells in the Philippines will cease to flow if the casing is continued even a few meters above the ground surface; that is to say, if such wells had been drilled from a slightly higher elevation, it would have been necessary to pump them. It follows that, other things being equal, the lower of two possible sites is preferable. However, the possibility of surface contamination should be kept in mind in this connection. A well on low ground is more often contaminated by surface waters than one on higher ground. It is true also that a well should not be located too near the seashore in an attempt to get it on low ground. Too often in such a location the well encounters brackish water.

Through the coöperation of the Bureau of Public Works the Bureau of Science has had access to drillers' logs for about 700 artesian wells. Samples of the drill cuttings have been submitted for examination in the cases of about half of these wells. These data, and a knowledge of the general geology of the Philippines, are made the basis of the following discussion.

For their consideration in relation to artesian waters the geologic formations of the Philippines may be classed and summarized as shown in Table I.

LITTORAL AND ALLUVIAL DEPOSITS

A large proportion of the population of the Philippines lives in regions in which the land is made up of littoral and alluvial deposits. The important areas of alluvium are found in great structural valleys like the Central Plain of Luzon, the Cagayan Valley in northern Luzon, the Bicol Valley in southeastern Luzon, the Iloilo Plain in Panay, and the Cotabato and Agusan Valleys in Mindanao. The littoral deposits make up the coastal plains which fringe many of the islands, like the plain upon which the town of Cebu is located. The structural valleys have been filled up by loose clays, sands, and gravels carried down from the adjacent highlands by shifting streams and deposited along an ever-advancing shore line. The coastal plains have been built up in the same way; in many cases they rest upon a base of coral reefs, which have grown up offshore from the various land masses. Both the filled structural valleys and the coastal plains combine alluvial and littoral deposits in their structure, since the alluvium carried by streams was deposited largely at the seashore where part of it was worked over again by wave action. In either situation the littoral and alluvial deposits are surprisingly thick; in very few cases have wells passed through them into the underlying formations.

TABLE I.—*Geologic formations in the Philippines and their relation to artesian-water supplies.*

Formation.	Extent of formation and degree to which it is populated.	Distribution of formation.	Character as a source of artesian water.
Littoral and alluvial deposits	Extensive and densely populated; therefore, important.	Seacoast and low-lying plains; all coastal plains: Central Plain, Cagayan Valley, Bicol Valley, on Luzon; Iloilo Plain, Panay; Agusan and Cotabato Valleys, Mindanao, etc.	Good; a majority of shallow wells in it are successful; source of most of artesian water now obtained, but many unsuccessful wells have been drilled in it.
Coralline limestone	Extensive and densely populated in the Visayans; fairly important.	Seacoast: Cebu, Samar, Bohol, Negros, etc.	Fair only; many wells are dry, some salty.
Volcanic breccia and agglomerates	Fairly extensive, but only fairly well populated.	Mountainous and high plateau areas throughout the Islands.	Fair only in general; some types are commonly water-bearing.
Bedded volcanic tuff	Fairly extensive; densely populated	Southwestern Luzon	Very good; some of the best wells obtain water from this formation.
Tertiary sedimentaries	Extensive; fairly well populated only	Interior and mountainous regions; coal- and petroleum-bearing regions generally; Samar.	Bad; dry formation full of salt.
Massive igneous rocks	Extensive, but not usually densely populated.	Interior and mountainous regions generally.	Very bad.
Metamorphic rocks	Limited extent and sparsely populated; unimportant.	Interior and mountainous regions	Bad.

A majority of the wells drilled by the Bureau of Public Works have penetrated these classes of material. A majority also of the successful wells have obtained their water from sands and gravels of littoral or alluvial or combined littoral and alluvial origin. It cannot be said, however, that littoral and alluvial deposits are uniformly productive of artesian water. Such deposits are irregular, and individual beds do not extend over large areas. On the contrary, the formation is characterized by narrow lenses of sand or gravel or clay, such as would be expected in the beds of modern streams or along beaches. It is due to this feature of littoral and alluvial deposits that so often a flowing well will be secured adjacent to a drilled hole which has obtained no water or only pumping water. A striking example is the case of two wells drilled within 50 meters of each other between the Philippine General Hospital and the Bureau of Science in Manila. The first well reached a depth of 178 meters and obtained only 113 liters of water per minute. The second well obtained 322 liters per minute at a depth of only 137 meters. On the completion of the second well work was resumed on the first well in an attempt to get water at the 137-meter horizon, but all efforts to this end failed. Neither of these wells flowed, but numerous experiments have demonstrated that in this class of deposits flowing wells, nonflowing wells, and dry wells may be situated side by side.

As has been said, littoral and alluvial deposits are made up of loosely consolidated sands, clays, and gravels. The loose character of the formation is responsible for the commonly noted phenomenon that in wells situated near the coast line the level of the water in the well varies with the stage of the tide in the adjacent sea. The fresh water in the upper part of the land mass is always percolating through porous beds toward the sea, and in the region of the seashore it is in some measure in a condition of hydrostatic equilibrium with the sea water, which saturates the porous beds outcropping on the sea floor. The rising tide actually increases the hydrostatic pressure on the ground water in the adjacent porous beds. This effect is especially marked where an old coral reef has been included between the deeper beds of the formation, because the loose structure of the coral reef affords unusually free passage for water.

Another factor which must be considered in connection with littoral and alluvial formations is the possibility of obtaining salt water in wells adjacent to the coast. Littoral deposits are contaminated by the salt water in which they were formed. Close to the coast line percolation of the fresh ground water may not have been extensive enough to have removed all the original salt, particularly where the formation contains clay, which is not easily permeable. Salt water is almost inevitably encountered at depth in wells near the coast line. The ground-water circulation appears to be most vigorous at depths generally less than 180 meters. Consequently, if potable water is encountered in littoral or alluvial deposits at depths of from 60 to 150 meters, it is usually advisable to make arrangements to use this water even though it be of limited quantity and require pumping, rather than to continue drilling in the hope of obtaining flowing water or water in greater quantity at extreme depths. Occasionally, where it has been possible to case out salt water, wells have been deepened and have obtained fresh water at lower levels, but as a rule, fresh water has not been found below salt water.

The discussion of alluvial and littoral deposits and combinations of these two classes of deposits may be extended and applied to intermingled alluvial, littoral, and fragmental volcanic material as well. Volcanic tuffs are often and extensively interbedded with alluvium and with littoral deposits in the Philippines; less frequently volcanic breccias and agglomerates alternate with alluvial or littoral material. Volcanic tuffs, as a matter of fact, usually contain interbedded alluvium, and similarly alluvium usually includes some volcanic tuff. The combinations of these several classes of material yield water about as commonly and under about the same conditions as littoral and alluvial deposits themselves.

CORALLINE LIMESTONE

Coralline limestone is generally dry where it occurs over extensive areas and in thickness. It is so porous and so thoroughly jointed and cavernous that water percolates through it with little hindrance. Only in coralline limestone that is interbedded with impervious beds of clay, marl, or other material is water confined so as to be available under hydrostatic pressure. Fortunately a great deal of the recent coralline limestone in the Philippines is interbedded with impervious material and, therefore, can often be made to yield water. Coral reefs have been found in buried littoral deposits, and in this position were saturated with water under pressure. More commonly coral reefs have been found in deposits of water-laid volcanic tuffs in relations which made the coral reef a natural reservoir for ground water. But the commonest condition under which water has been obtained from coralline limestone is that of interbedded coralline limestone and clayey marl. The thick marl beds are impervious and confine the water in the intervening porous coral-reef members of the series.

Coralline limestone is most abundant in the Visayan Islands, especially in Cebu and Bohol. On both these islands it includes marl beds. Good wells have been obtained in this formation in only about 50 per cent of the trials made. The chance of encountering salt water is great if the well is drilled to a depth which carries it much below sea level. In drilling through coral, the hole should not advance far beyond the casing, even though the wells may stand up well, and especial watch should be maintained for impervious layers which may act as confining agents.

VOLCANIC BRECCIAS AND AGGLOMERATES

Volcanic breccias and agglomerates, made up of varyingly coarse and fine fragmental material embedded in tuff, are very common in the Philippines. These rocks have usually been deposited on the sea floor and, therefore, have been worked over and roughly stratified by water, but heterogeneous breccias and agglomerates of subaërial deposition are also known. These rocks are found in the immediate vicinities of old volcanoes and along lines of former volcanic activity. Much of the material is indurated and impervious, but an equal proportion, perhaps, is loose and porous.

In massive breccias or agglomerates there is only slight chance of obtaining artesian water, but where the fragmental material has been deposited on a sea floor, and is, therefore, somewhat bedded, artesian water may be obtained. Wells on the southeastern and eastern shores of Laguna de Bay have yielded good flows from this class of rock. There is a considerable area of bedded volcanic agglomerate around the base of Mount Isarog in Camarines which ought to yield water, and likewise in northern Camarines and in Sorsogon there are places at which it is suspected rocks of this nature are water-bearing. On the whole, however, volcanic breccias and agglomerates are rather uncertain territory for the artesian-well driller.

Mineralized water is often encountered in massive volcanic agglomerate. Hot springs and other evidences of solfataric action are associated with these rocks, so that in addition to the possibility of encountering no water there is the further chance that if water is encountered it may be too thoroughly mineralized to be potable.

BEDDED VOLCANIC TUFF

Bedded volcanic tuff is found extensively in southwestern Luzon and has proved to be particularly reliable as a source of artesian water. This tuff has not been indurated nor consolidated through folding processes; it is distinctly bedded and generally porous, but the successive beds are varyingly fine-grained, so that conditions for confining water under some pressure are very good. Many of the wells in the bedded tuff have yielded flows, and a great majority have yielded either pumping or flowing water. The bedded tuff formation is, perhaps, more uniformly water-bearing than any other of the Philippine rock series.

TERTIARY SEDIMENTARIES

The Tertiary (Miocene) sedimentaries consist of shales, sandstones, conglomerates, and limestones. The formation is encountered in various parts of Luzon; it makes up nearly the whole of the area of Samar; and it is important in Leyte, Cebu, Panay, and in parts of Mindanao. Coal and petroleum are found only in the Tertiary sedimentaries in the Philippines, and the distribution of these minerals may be used as a guide in this connection. The shales and sandstones are made up in large proportion of volcanic material. The series as a whole is indurated and close-grained; consequently it carries but little water. Moreover the fine-grained beds retain a great deal of their original salt content, and this contaminates any water which is obtained from them. Only a small number of wells have penetrated the sedimentary series, and only a small proportion of these have been successful. Where this series of beds constitutes the underlying formation, a serious effort should be made to obtain potable waters in the surface alluvium if it is available. Deep wells are to be undertaken only as a last resort.

It must be admitted that some artesian water has been obtained from the sedimentary rocks, but the flows are invariably small, and no eminently satisfactory wells have been drilled into the formation. The sandstones and the conglomerates yield water under favorable conditions, but even these rocks are too dense to be of great promise. The limestone members of the series are very cavernous and jointed, and water percolates through them readily. The lower limestone, which is very close to the base of the sedimentary series, is undoubtedly the most important possible source of artesian water in this formation.

At its outcrop this limestone is corroded and jointed until it is a very porous rock. The sedimentary series is usually found flanking the cordilleras and dipping away from them, so that very often this basal limestone is exposed in a region of heavy rainfall and lies at an angle which accelerates the percolation of water along it. If the limestone in this relation were penetrated by a well, it ought to yield water copiously. The difficulties are that the basal limestone is thin, discontinuous, and broken by faulting; that inasmuch as its porosity in surface exposures is due largely to solution, the limestone may not be porous below the permanent level of ground water; and finally, that its stratigraphic position is such that it is commonly too deeply buried, except in mountainous and consequently uninhabited regions, to be accessible by drilling. The conditions afford a chance, however, which should be tested when opportunity presents.

MASSIVE IGNEOUS ROCKS

Massive igneous rocks abound in all of the truly mountainous portions of the Philippine Islands. Igneous rocks, wherever present to the exclusion of other rocks, constitute the formation least favorable to the accumulation of potable artesian water. They are impermeable to water because of their dense nonporous texture and the absence of bedding planes. It is generally immaterial in this connection whether the igneous rock is of the deep-seated, holocrystalline type, such as the diorites, gabbros, peridotites, and occasional granites, or is one of the surface lava flows, such as the widely distributed andesites and less common basalts, rhyolites, and dacites, although infrequently solidified lava flows are so vesicular and porous as to be permeable to water. Very rarely do common igneous rocks yield water in quantity. No Philippine wells have encountered water in massive igneous rocks, although a dozen, perhaps, have been drilled into them. Minute quantities of water are contained along fractures and joints in igneous rocks, and often mineralized water is encountered in the occasional veins and shear zones; otherwise the rocks are almost invariably dry. Obviously, therefore, igneous rocks are to be avoided in choosing sites for artesian wells.

METAMORPHIC ROCKS

Metamorphic types of rocks are represented in the Philippines principally by schists, with subordinate gneisses and marbles. Because of their dense nature metamorphic rocks are not common sources of artesian water. In the Philippines they are of limited distribution and consequently unimportant; as yet no wells have been drilled into them. Water might be obtained from buried marble, which is often cavernous, but schist and gneiss would probably be found to be dry.

Schists and gneisses, together with massive igneous rocks, are the basal formations in the Philippine rock series and will, therefore, be encountered ultimately in practically any locality in the Islands if the drilling proceeds to a sufficient depth. Since they are devoid of water, no attempt should be made to continue drilling once these formations are encountered.

PETROLEUM AND RESIDUAL BITUMENS IN LEYTE[1]

By WALLACE E. PRATT
(From the Division of Mines, Bureau of Science, Manila, P. I.)

ONE PLATE AND 2 TEXT FIGURES

CONTENTS

INTRODUCTION.
SITUATION.
PHYSIOGRAPHY.
GENERAL GEOLOGY.
STRATIGRAPHY.
  Alluvial and littoral deposits.
  Malumbang series.
  Canguinsa clay-tuff.
  Vigo shale.
  Intrusive rocks.
STRUCTURE.
OCCURRENCE OF THE PETROLEUM AND RESIDUAL BITUMENS.
CHARACTER OF THE PETROLEUM AND RESIDUAL BITUMENS.
SOURCES AND PROBABLE QUANTITIES OF PETROLEUM AND RESIDUAL BITUMENS.
THE UTILIZATION OF THE RESIDUAL BITUMENS.
SUGGESTIONS FOR EXPLORATION.
SUMMARY.

INTRODUCTION

The existence of petroleum in Leyte became known about the year 1890. In 1892, according to old Spanish records, an Englishman, named White, sought exclusive permission to exploit petroleum deposits in the Philippines and to refine the petroleum obtained therefrom. In his petition the applicant specified the northwestern part of Leyte and the Islands of Cebu, Bohol, Negros, and Panay as territory to be explored. Becker,[2] quoting various Spanish authorities, states that petroleum had been found in the jurisdiction of the town of San Isidro, Leyte. Sir Boverton Redwood[3] was informed by a Mr. Warren that petroleum was known to occur near the town of Villaba, Leyte. The people of the town of Villaba remember an attempt at exploitation about the year 1896 on a well-known seep near the barrio of Jinagnatan. Apparently this work, the men in charge of which are said to have been Belgians, was without result; certainly no wells of any depth were drilled. Adams[4] mentions the reported occurrence of petroleum at Villaba, but had no opportunity to verify the reports.

---

[1] Received for publication June 16, 1915.

[2] Report on the geology of the Philippine Islands, *21st Annual Rep. U. S. Geol. Surv.* (1901), pt. 3, 107, reprint.

[3] Petroleum and its Products. Charles Griffin & Co. Ltd., London. 2d ed. (1906), 56.

[4] *This Journal, Sec. A* (1909), 4, 355.

Attention was recalled to the Villaba region by the reported discovery of asphalt there in 1913. The original discovery was made by a Filipino ranger in the forest service in mountainous country about 10 kilometers northeast of Villaba. The material found by the forest ranger is a brittle, solid bitumen, brownish black in color, schistose or irregular in fracture, and high in its content of paraffin. This discovery was followed immediately by a period of active prospecting and claim location. A number of other outcrops of material similar in character to the forest ranger's outcrop have been located, and other outcrops and seepages of hydrocarbons, ranging in character from petroleum itself, through viscous liquids and semisolids, to hard, coallike bitumens, are now known. Bitumen-impregnated limestone and sandstone have also been found. A majority of the later discoveries are nearer to the seacoast and in less mountainous country than the first find, a feature which has stimulated prospecting.

At the present time there are about 30 claims in the district. Approximately one half of these are individual claims, 8 hectares in area; the remainder are association claims, 64 hectares in area. A majority of the claim holders have pooled their interests and have incorporated under the name of The Leyte Asphalt and Mineral Oil Company, Limited.

The notes upon which the present paper is based were made during a visit of a week's duration in May, 1915.

SITUATION

Villaba is situated on the western coast of northern Leyte. The petroleum seep whose existence is noted by Becker and by Redwood lies near the seacoast about 4 kilometers north of Villaba; it is just inland from Burabod Point between the barrios of Jinagnatan and Campocpoc. The solid bitumens first discovered occur at the western base of the ridge surmounted by Mount Benao and to the south of that mountain in the valley of one of the streams at the head of Butason River. Other seepages of petroleum, which were evidently not known to the Spaniards, have recently been found at the head of the valley east of Villaba at a distance of about 4 kilometers from that town. Other outcrops of solid bitumens have been found around the western base of Mount Benao, and viscous bitumens seep from the banks of a creek which flows into Butason River farther west than the outcrop first discovered. A mixture of solid bitumen and fragments of clay-tuff has been discovered in the edge of the town of Villaba itself. This deposit appears to be of considerable extent laterally. To the south of Villaba at a distance of about 3 kilometers there is a large outcrop of bitumen-impregnated limestone, and east of this occurrence there is another small outcrop of solid or semisolid bitumen. Finally, viscous black bitumen has been found just inland from the barrio of Tabubunga, 10 kilometers south of Villaba. Both petroleum and solid bitumen are reported from other places in northwestern Leyte, but these reports were not verified. Some of them appear upon examination to be unreliable, but in view of the geology of the region it will be surprising if other occurrences of petroleum and bitumens derived from petroleum are not discovered.

The principal known occurrences of petroleum and related bitumens, therefore, are distributed over an area 8 kilometers wide and 13 kilometers long. The peninsular portion of northwestern Leyte as far south as the barrio of Baliti is a geologic unit and should be included in the area which may contain petroleum, although surface indications of petroleum will probably not be encountered in the northern part of the peninsula, because there erosion has not removed the cover of rocks overlying the petroleum-bearing formation as it has farther south.

The vicinity of Villaba is shown on the accompanying map, fig. 2, together with all of the known bitumen outcrops and petroleum seepages. In fig. 1 northwestern Leyte is shown in outline. Both these maps are based on Coast and Geodetic Survey charts. The situations of the outcrops as shown on the detailed map were obtained by compass surveys.

PHYSIOGRAPHY

Northwestern Leyte is of only moderate relief—rarely do the elevations exceed 350 meters—but the valleys are deeply incised, and the slopes are usually steep. The topography reflects strongly the geologic structure—nearly flat-topped ridges and hills in the extreme north where the strata are level or only slightly inclined, and sharp points and knife-edged divides in the steeply dipping shales farther south. A resistant limestone near the top of the rock series withstands erosion, so that in places it becomes a base upon which remain little groups or rows of regular conical hills carved out of the softer overlying sandstone.

The rainfall is carried off by a number of small drainage systems, so that within the petroleum region there are no large streams. The headwaters of the river which reaches the sea

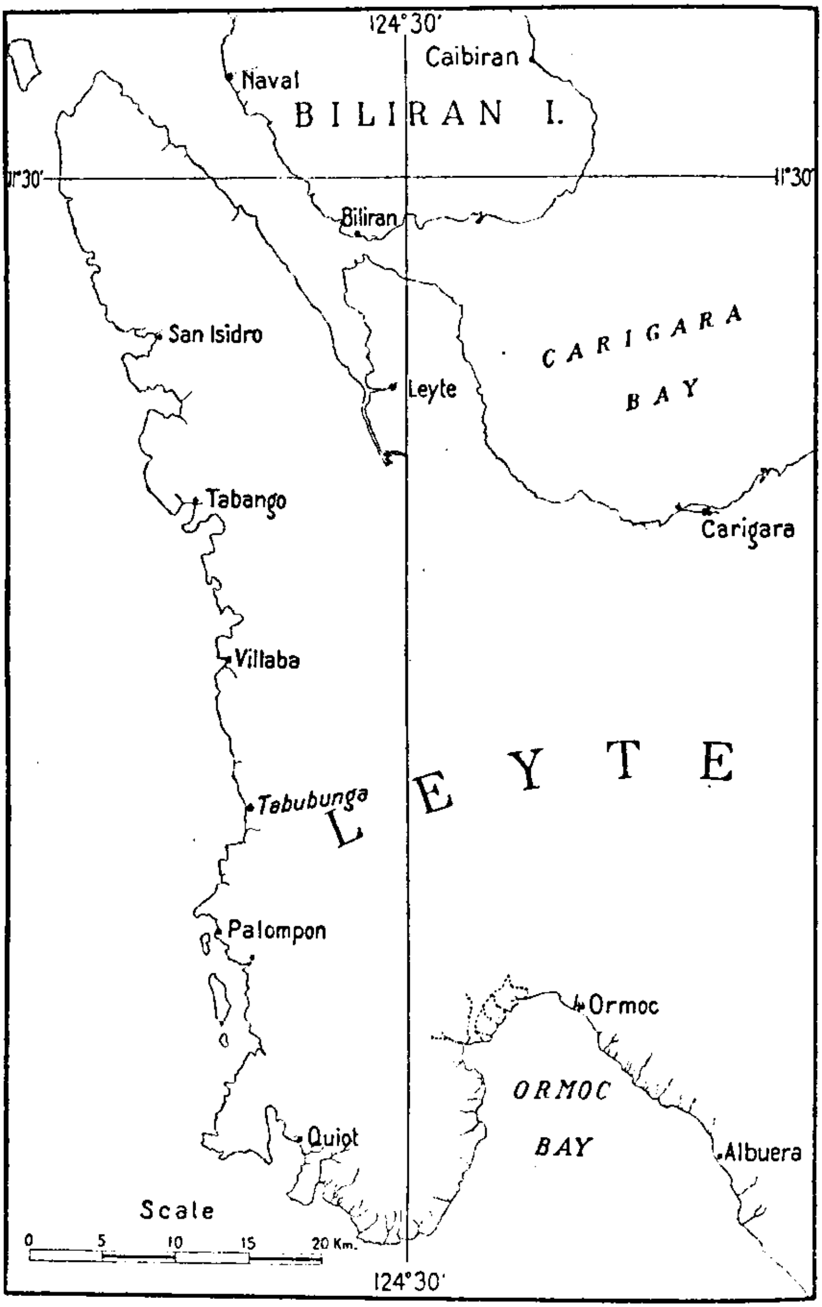

FIG. 1. Outline of northwestern Leyte.

at Ormoc are just south of Villaba, but the river does not attain a great volume within the confines of the petroleum-bearing territory. Likewise Butason River leaves the petroleum region behind before it attains any great size.

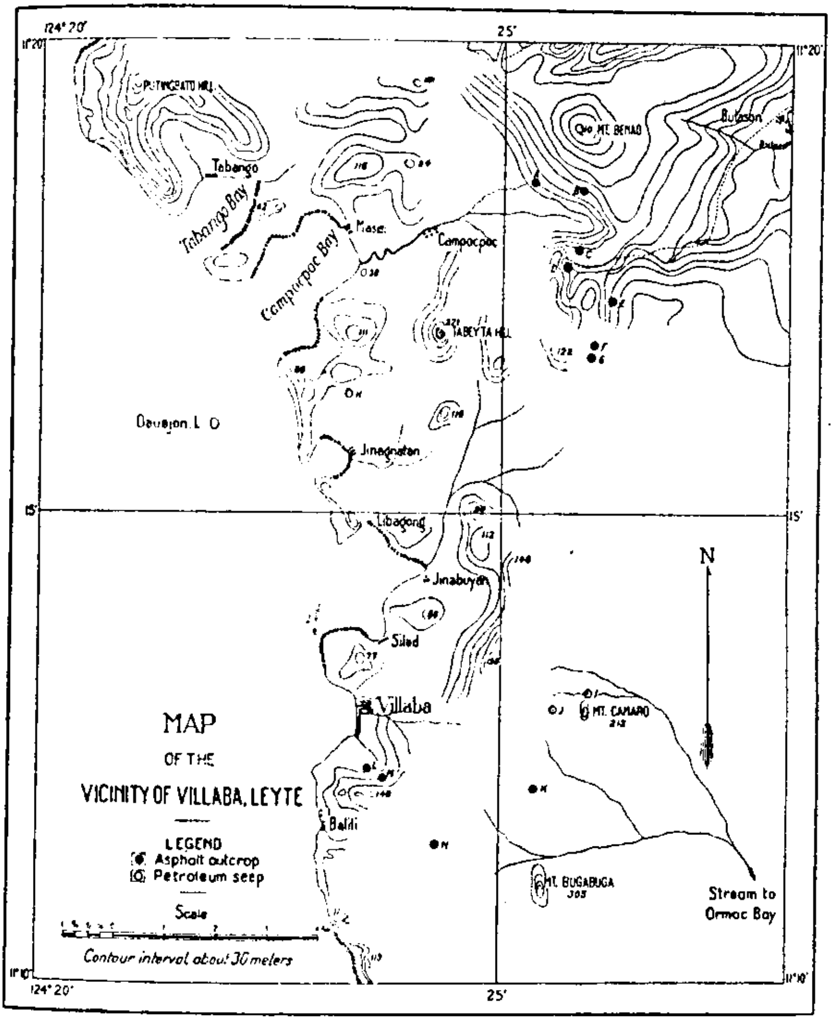

FIG. 2. Vicinity of Villaba, Leyte, showing the situations of outcrops of natural bitumens and seepages of petroleum.

The coast line of northwestern Leyte is generally regular and unbroken by indentations. The land mass rises abruptly from the seashore, and the streams are tidal for a comparatively short distance inland. In the vicinity of the petroleum-bearing area, however, the generally straight coast line is modified by a series of sharp reëntrants, including San Isidro Bay, Arevalo Bay, and Campocpoc Bay. Evidently these conspicuous indentations have resulted from local folding.

GENERAL GEOLOGY

The geologic formation in northwestern Leyte is predominantly sedimentary and belongs to the late Tertiary and Post-Tertiary series of rocks. The several divisions can be correlated directly with the stratigraphic column as worked out by Pratt and Smith[5] in the Bondoc Peninsula petroleum region in Tayabas Province.

Thin-bedded shales and subordinate thin beds of sandstone of lower Miocene or Oligocene age make up the base of the series. These beds appear to have been laid down unconformably over a complex of igneous and metamorphic rocks of undetermined age. The name Vigo shale was applied to the thin-bedded shale and sandstone series because of typical occurrences along Vigo River in Tayabas. Petroleum is found in the Vigo both in Tayabas and Leyte.

Overlying the Vigo with some degree of unconformity is a massive or imperfectly bedded formation of clay-tuff and tuff-sandstone, which was designated as the Canguinsa sandstone in Tayabas. This formation yields petroleum and derived bitumens in Leyte, although it is barren or only faintly petroliferous in Tayabas.

Limestone and calcareous sandstone are encountered with apparent conformity, above the Canguinsa, in both Leyte and Tayabas. These rocks are known as the Malumbang series, and they mark the top of the stratigraphic column except for recently elevated coral reefs, littoral deposits, and modern alluvium. The Malumbang series contains no petroleum in Tayabas, but in Leyte it has been impregnated with petroleum in at least one place with the formation of bituminous limestone and bituminous sandstone as a result.

The total thickness of the sedimentary formations in Tayabas was estimated at from 1,700 to 1,800 meters, and the sections which can be measured in Leyte show corresponding thicknesses.

The presence of several small intrusions of andesite and andesite-agglomerate was recorded in the report on the Tayabas region. In the Leyte field intrusions of this class are much more prominent and numerous. One of the most conspicuous hills in the vicinity of Villaba, namely, Mount Tabeyta, consists of andesite and andesite-agglomerate, and a half-dozen smaller intru-

[5] *This Journal, Sec. A* (1913), 8, 301 et seq.

sions, distributed throughout the petroleum-bearing region, were observed.

The sedimentaries in northwestern Leyte are generally tilted so as to have a strike of north 60° west with dips of from 10° to 20° at right angles to this line in either direction; locally the strata have been thrown into sharper folds in which, however, the general west-northwest strike is maintained. At places along the coasts even the general strike is lost, and the attitude of the beds is widely different over short distances. The more intense folds are in the intruded areas and are probably accompanied by faulting.

STRATIGRAPHY

Table I shows the stratigraphy of the Tayabas petroleum region as worked out by Pratt and Smith.[6] As modified in the following discussion, the table serves admirably for the Leyte petroleum region, the correlation of the principal divisions being perfect.

ALLUVIAL AND LITTORAL DEPOSITS

Alluvium is of minor occurrence in northwestern Leyte and demands little attention. Sand and clay derived from the sedimentary rocks, with pebbles from the intrusives and coralline limestones, border the lower courses of the streams. Raised coral reefs are encountered along the coasts and indicate an elevation of the land mass continuing into recent time. Fragmental coral and other littoral débris have been elevated with the reefs, and the deposits have a roughly bedded structure in which the dividing planes are frequently inclined at considerable angles.

MALUMBANG SERIES

The Malumbang series has not been studied as closely in Leyte as it has in Tayabas; in the last-named region it was found to be nonuniform both in thickness and in character. An upper and lower limestone with an intervening sandstone were found at some places in Tayabas, but at other places the lower limestone appeared to be missing, and the sections rarely included all three divisions. In Leyte the series is similarly inconstant in character. It can hardly be described more definitely than as an irregular succession of calcareous beds, ranging from chalky limestone through calcareous sandstone to coralline limestone. The chalky beds are more prominent in Leyte than in

---

[6] Op. cit., 312.

TABLE I.—*Provisional scheme of stratigraphy. Bondoc Peninsula, Tayabas.*

Series.	Formation.	Subdivisions and character.	Thickness.	Characteristic fossils.	Geologic condition of deposition.
			Meters.		
Recent	Alluvium	Clay, sand, gravel, and travertine	0-10		Fluviatile.
Pleistocene and Recent	Coral reefs and littoral deposits.	Raised coral reefs, beaches, etc	0-15	*Trochus fenestratus*, *Cerithium nodulosum*, *Telescopium* sp., *Conus flavidus*.	Seashore deposits during slow elevation.
Unconformity					
Pliocene and upper or middle Miocene.	Malumbang series	Upper limestone. Coralline to sandy	20-50	*Pyrula gigas*, *Lucina bacauensis*, *Cerithium* sp., *Solecurtus grandis*, *Spondylus imperialis*, *Operculina costata*, *Bulla ampulla*, *Pecten senatorius*, *Lithothamnium ramosissimum*.	Shallow seas, clear at times.
		Cudiapi sandstone. Bedded, calcareous, yellow to brown.	50-100		
		Lower limestone, white to yellow, coralline in part.	0-20		
Middle or lower Miocene.	Canguinsa sandstone.	Blue to gray, massive, clayey sandstone with gray calcareous sandstone and minor beds of limestone locally. A single small outcrop of volcanic agglomerate in base, not of general occurrence.	50-160	Large lepidocyclinas, *Cycloclypeus communis*.	Nonuniform conditions; both deep or quiet and shallow seas indicated; local extrusion.
Unconformity. Mechanical discordance and possible erosion.					
		Sandstone and fine sandy conglomerate, in alternate beds.	(?)	*Mitra* sp., *Pyrula* sp	
		Bacau stage. Massive or imperfectly bedded, bluish black shale with minor sandy zones. The principal oil seeps are associated with the Bacau stage, and shallow wells have obtained fair showings of oil in it.	50-160	*Conus loroisii*, *Conus striatellus*, *Globigerina*, *Conus hochstetteri*, *Tapes rimosa*.	Local extrusion. Shallow seas, gradual sub-

Lower Miocene or Oligocene. (?)	Vigo shale	A single outcrop of volcanic agglomerate at this horizon, but not of general occurrence. Gray shale, black shale, yellow and brown sandy shale, and sandstone interbedded in thin layers. Traces of oil and gas. Possible oil horizon in unexposed base. A single small exposure of volcanic agglomerate; not of general occurrence.	[a]1,400	*Globigerina*, *Polystomella*	sidence. Water deepened late in the period, but became very shallow at close.
Eocene		Concealed or lacking			
Unconformity					
(?)		Basal conglomerate over diorite			

[a] Base not exposed.

Tayabas. They form smooth white faces, which are numerous along the western coast. They are encountered both above and below the calcareous sandstone, while the coralline limestones are usually above the sandstone. The chalky limestone appears to contain very fine tuff in some exposures.

South of Villaba and east of Baliti the Malumbang series has been impregnated with bitumen. The bituminous limestone and bituminous sandstone so formed outcrop at the head of a cañon near the summit of the hills. It is probable that the cañon marks a fault, since Vigo shale is exposed in the wall opposite the bitumen-impregnated face. Here the Malumbang series is at least 50 meters thick and is clearly conformable over the Canguinsa, both formations dipping at low angles to the south. The lower beds are calcareous sandstone (lower limestone missing), while the upper part of the series is fragmental, coralline limestone. Elsewhere in Leyte, especially on the northern part of the peninsula, the Malumbang series is much thicker and may attain a maximum of 200 meters.

In distribution the Malumbang may be said to be confined to the tops of the hills along the coast in the southern part of the region, extending inland farther north until it is intact across the north end of the peninsula. It is especially heavy on the northeastern coast of the peninsula.

CANGUINSA CLAY-TUFF

The Canguinsa as it occurs in Tayabas is a light gray, light brown, or light blue, massive clay-tuff, or clayey tuff-sandstone, both of which, although soft, are dense and tough as a result of their close, fine-grained texture. The rock is imperfectly bedded at places; elsewhere it is massive. It is usually slightly calcareous and contains numerous small fossils (Table I). It breaks with a subconchoidal fracture and weathers into fragments with concave faces, which are smooth and greasy to the touch and emit a faint odor of bitumen. At places toward its base the Canguinsa becomes fissile and takes on something of the character of the Vigo shale.

This description applies perfectly to the Canguinsa in Leyte, where it is in every respect similar to the Tayabas occurrences. A fact which escaped mention in the report on the Tayabas field, however, is that the Canguinsa contains a large proportion of volcanic tuff of varying fineness. In places it is a clay-tuff; at other places, a tuff-sandstone. The individual grains of tuff are sharp fragments of glass, calcic feldspar, and subordinate quartz.

The commonest fossil in the Canguinsa in Leyte is a species of *Globigerina,* a low form of animal life which builds a very small, spherical shell of calcium carbonate. These fossils were noted in the upper part of the Vigo shale in Tayabas, and the study of that field brought forth the suggestion that the petroleum, which undoubtedly comes from the Vigo, might have originated through the decomposition of the organic matter which the shells once contained. The Canguinsa in Leyte appears to contain even more examples of *Globigerina* than the Vigo; possibly 5 per cent of the area on an average surface of a fragment of Canguinsa clay-tuff from Leyte is covered by these small spheres.

No petroleum was detected in the Canguinsa in Tayabas, but in Leyte a majority of the outcrops of bituminous residues from petroleum occur in the Canguinsa, and at one place petroleum itself seeps from a tuff-sandstone phase of the Canguinsa.

The Canguinsa is the surface rock over the larger part of the Leyte petroleum field. It outcrops in the lower parts of the hills which are capped by the Malumbang series and is intact above the Vigo shale, except to the east and south of Jinabuyan and Villaba. The ridge which culminates in Mount Benao consists principally of Canguinsa rocks—clay-tuffs and clayey, tuff-sandstones. The western face of Mount Benao affords the best section of the Canguinsa observed in Leyte. In this region its thickness is at least 300 meters, a figure which is comparable with the estimated thickness of the same division of the Tayabas sedimentary column.

VIGO SHALE

The Vigo shale consists of alternating, thin, perfect beds of shale, sandy shale, and sandstone. The strata are differently colored—dark gray, brown, and yellow—and outcrops often present a variegated appearance. Toward the top of the formation, dark-colored fine-grained shale, in thicker and less perfectly defined beds, is predominant. This upper shale was referred to as the Bacau stage of the Vigo in the report on the Tayabas field, having been differentiated there because it appears to be more petroliferous than the underlying beds. The Vigo is like the Canguinsa in that its beds, both shale and sandstone, appear to contain considerable tuffaceous material. The sandstone beds, for instance, are made up of sharp or slightly rounded fragments of feldspar, ferromagnesian minerals, glass, and quartz. Unlike the Canguinsa, on the other hand, the Vigo rocks are somewhat indurated and usually fissile, so that they split into thin laminæ on disintegration. The fine-grained shale at the top of the Vigo, however, is not fissile and except for its darker color resembles the overlying Canguinsa. It weathers into ellipsoids, the forms of which stand out along the exposed edges of the beds, with their major axes in the plane of the stratum.

The Vigo shale is probably about 1,000 meters in maximum thickness in Leyte, although complete sections were not observed. Undoubtedly the thickness varies, because it is known to overlap, unconformably, the formation upon which it rests. The most extensive exposures lie to the east and south of Villaba, while smaller outcrops are encountered at various places in the surrounding country.

Petroleum seeps from the Vigo at half a dozen places in Tayabas. Apparently it always comes from the upper part of the formation. In Leyte two petroleum seeps were found in the Vigo shale, and a very heavy, black, oil-liquid bitumen was encountered in sandstone, closely above the basal complex upon which the Vigo lies. The solid bitumens which occur in the overlying Canguinsa were nowhere observed in the Vigo.

INTRUSIVE ROCKS

The intrusive rocks in Leyte are principally andesites and andesite-breccias. Similar intrusions were observed in Tayabas, and the rocks of which they consist were described in the report on that region. In Leyte the andesites are usually porphyritic with phenocrysts of ferromagnesian minerals and occasional calcic feldspars in a light-colored groundmass. Other specimens are dark-colored, fine-grained, homogeneous rocks.

A single outcrop of an igneous rock, which appears to be diorite, is encountered at petroleum seepage I. This rock is somewhat decomposed, is holocrystalline in texture, and consists essentially of calcic feldspars and hornblende or pyroxene. The outcrop is at a low horizon in the Vigo shale and may represent a part of the basal igneous complex instead of an intrusion.

The intrusive nature of the andesites is indicated by their relation to the strata in the surrounding sedimentaries; by the presence in at least two places of adjacent springs of warm mineralized water which emits an odor of hydrogen sulphide; by rare fragments of quartz, chert, and partly baked shale in the rocks surrounding the intrusion; and in the case of the Mount Tabeyta intrusion, by remnants of a calcite- and quartz-cemented shale-breccia surmounting the andesite.

The intrusions penetrate the Vigo shale and the Canguinsa clay-tuff. Mount Tabeyta and the isolated conical hill at the mouth of Campocpoc River are the largest and most conspicuous of the intrusions, but there are numerous smaller outcrops east and south of Villaba.

It is believed that the intrusions have been instrumental in driving the petroleum upward through the surrounding rocks. One of the observed petroleum seeps is on the contact of an apparently intrusive holocrystalline rock in the Vigo shale. All the petroleum and solid bitumen occurrences are near intrusions, and viscous or semiliquid bitumen is found in concretions and brecciated concretionlike bodies, the origin of which may reasonably be attributed to solutions given off by buried intrusions.

More detailed descriptions of each of the formations represented in Leyte will be found in the report cited on the Tayabas field, and other observations are recorded in the descriptions of the occurrences of the hydrocarbons in the present paper. The age of the various divisions was determined by Smith from his study of the included fossil remains as follows: Alluvium and littoral deposits, Recent; raised coral reefs, Recent to Pleistocene; Malumbang series, Pliocene and upper or middle Miocene; Canguinsa clay-tuff, middle or lower Miocene; Vigo shale, lower Miocene or Oligocene. The intrusive rocks are younger than the Canguinsa and are evidently younger than the Malumbang series if they are responsible for the dispersion of the bituminous matter which is observed to impregnate part of the Malumbang series south of Villaba.

STRUCTURE

The structure of the Leyte petroleum region has been complicated by the intrusions which have penetrated the bedded rocks. The predominant strike is west-northwest. The dips are usually not greater than 30°, but locally they exceed this angle, especially in the Vigo shale, which commonly shows a greater inclination than the overlying beds. There are lines of local folding with dips in opposite directions on either side. Most of these folds trend west-northwest in the direction of the general strike, but this is not universally true. Along the coasts there is a tendency at several places for the strata to dip seaward, the strike corresponding to the general direction of the coast line.

The bitumens and the intrusive rocks alike appear in or near arches or domes in the structure. Nowhere are they found in clearly defined synclines.

There is an anticline with west-northwest axis near the head of Butason River. Outcrop D lies on the southern limb, and outcrops A and B lie on the northern limb of this fold. At outcrops E, F, and G, however, the dip is uniformly north-northeast, showing that the fold does not persist far eastward. Between seepages I and J, again, there is a west-northwest-trending anticline in the Vigo shale, with Mount Camaro lying on its crest. The seepage at I on the northern limb of this fold is marked by igneous rocks which may be either intrusive or a part of the basal complex which underlies the Vigo shale. The outcrop N is on a fault trending west-northwest, along which there is also a small intrusion and from which the strata dip away on either side.

The southern part of the petroleum region, therefore, appears to contain a number of small folds, the majority of which have not yet been delineated. There are probably also more faults than have been detected. The intrusions, to judge from their distribution, are related to the folds in origin. In the northern part of the peninsula the folding processes have been less intense, and low broad folds would be expected in this territory.

Both in Tayabas and in Leyte there is a discordance between the Vigo shale and the overlying Canguinsa. This discordance is evidenced by an abrupt flattening in the angle of dip on passing from the Vigo to the Canguinsa in sharply folded areas. The dip is constantly in the same direction, but is less pronounced in the upper rocks than it is in the Vigo. Where the folding processes have not been intense, and the dips are consequently not steep, there is apparent conformity between the two formations. The possibility of an unconformity between the Vigo and the Canguinsa was discussed at length in the report on the Tayabas region. The question is important if, as is suggested, the Vigo shale is the petroleum-bearing formation. No conclusive evidence of an erosional unconformity was discovered, and it is, therefore, suggested that the observed difference in the angles of dip in the two formations might be explained as a mechanical discordance. It is conceived that the perfectly and closely laminated character of the Vigo shale would tend to cause it to respond more readily and more completely to processes of folding than would the heavily bedded or massive Canguinsa. The result might be a crumpling or wrinkling of the Vigo shale, which would be less plainly manifested in the more competent arch of the overlying Canguinsa.

Whether the unconformity between the Vigo and the Canguinsa is erosional or only a mechanical discordance is not conclusively determined. If it is erosional, there may, of course, be structures in the Vigo shale where it is covered by the upper rocks which are not reflected on the surface. Likewise there would be an overlap of the upper rocks on the upturned edges of the Vigo. If the discordance is only mechanical, there may still be a slight overlap on the limbs of steep folds, but the structure as determined by the attitude of the upper beds must be practically the same in the underlying, petroleum-bearing Vigo shale.

OCCURRENCE OF THE PETROLEUM AND RESIDUAL BITUMENS

In Leyte petroleum is encountered at two places: namely, seeping from the upturned edges of the Vigo shale and oozing from the base of a hill which consists of a clayey tuff-sandstone belonging to the Canguinsa. Residual bitumens occur in the Canguinsa and in the Malumbang series; one questionable outcrop of solid bitumen was observed in loose débris which appears to overlie the Vigo shale, and a heavy, black oil or viscous bitumen was found in sandstone near the base of the Vigo.

The bitumens in the Canguinsa are encountered in five types of deposits: (1) solid bitumens in lenses or pockets which tend to follow bedding planes, but which also cross the bedding irregularly along fractures and cavities; (2) solid bitumens in regular fissures which penetrate the clay-tuff independently of bedding planes; (3) in nonuniform mixtures of bitumen-impregnated, clay-tuff fragments and subordinate solid bitumen; (4) viscous or semiliquid bitumen-cementing breccias of flintlike limestone, small domes of which protrude from the surface of the clay-tuff formation; and (5) viscous or semisolid bitumen filling the centers of hollow, cylindrical concretions which occur in the clay tuff, with their longer axes nearly vertical and at right angles to bedding planes. The bitumen in the Malumbang series has impregnated porous limestone and sandstone, forming what is known commercially as rock asphalt. The various occurrences both of petroleum and of residual bitumen, which are indicated on the map (fig. 2) by letter, will be described separately. Chemical data on the petroleum and the bitumens will be found in the discussion on the character of the bitumens.

Outcrops A and B are jet black, lustrous bitumens with conchoidal fracture, which have been mistaken by the Filipinos who live in the vicinity for coal. The bitumen has a specific gravity of 1.05, a black streak, and a hardness, at ordinary temperature, of not more than 2. It melts readily, intumesces, and flows imperfectly. Upon distillation it yields a delicate coke. The outcrops have been on fire at various times, either through spontaneous combustion or, more probably, through kindling from the grass fires which sweep the region nearly every year, and the clay surrounding them is baked to a red sinter at places. Both deposits are found in Canguinsa clay-tuff at the base of

Mount Benao, with at least 250 meters' thickness of this formation stratigraphically above them.

Outcrop A is in a creek which flows into Campocpoc River. Several exposures have been found at the surface, but attempts to follow them with excavations have failed. Evidently only loose débris or surface float from the true deposit, whatever its nature may be, has as yet been discovered. In all, perhaps one ton of bitumen has been recovered.

At B a small vertical fissure filled with solid bitumen has been exposed by a shaft about 3 meters deep. There are other outcrops of similar bitumen near by, but only the one has been opened enough to reveal its form. This fissure has sharp, regular walls and widens downward from 30 centimeters at the surface to 60 centimeters at the bottom of the opening. The bitumen is closely jointed at right angles to the walls, so that it is removed in roughly columnar fragments. A small lens of the clay wall was observed in the fissure surrounded by bitumen, and small seams of bitumen extend out from the fissure along joint planes in the clay, although there is no general impregnation of the surrounding walls. The fissure trends a little north of east across the beds of the Canguinsa, which strike west-northwest and dip about 20° north-northeast.

Outcrop C is identical in character with outcrop A. Nothing in place has been discovered, but pieces of black, shiny bitumen are scattered over the surface on the side of a hill of Canguinsa clay-tuff. Probably both at A and C fissures similar to the one at B will be found.

At D there are several outcrops of viscous, black bitumen along the bed of a small stream. The material varies from a semiliquid, through a sticky, viscous stage, to a rubbery semisolid. The largest outcrop is a dome of bitumen-cemented breccia about 1 meter in diameter, which protrudes nearly a meter from the surface of the Canguinsa clay-tuff in the creek floor. The bitumen binds together the rock fragments in the breccia and also occupies pores and vesicles in the fragments themselves. There are at least two other outcrops of the same character. A shallow excavation around the base of the larger dome shows that it continues downward through the clay-tuff beds. Apparently these breccia domes or chimneys penetrate the strata, although there is no evidence of disturbance in the clay-tuff surrounding them.

The outcrops are in the basal part of the Canguinsa, very closely above the Vigo shale. The dip in the surrounding rocks is about 30° to the south-southwest. A few hundred meters to the north the dip changes in direction to the north-northeast and continues unchanged to the region of Mount Benao. Thus an anticline is indicated, the axis of which trends west-northwest and lies close to the north of D outcrop. The southern limb of this fold is not persistent, north-northeast dips being again encountered at a distance of 1 kilometer south of the axis.

The fragments in the breccia are compact, flintlike rocks, which can best be described, perhaps, by likening them to portions of the clay-tuff hardened through impregnation by mineralizing solutions. That the hard rock may, indeed, have originated by some such process is suggested by the presence in the same neighborhood of peculiar concretions of the same flintlike material in the clay-tuff. These concretions, which have been spoken of as tubelike, are hollow, thick-walled, nearly vertical cylinders, piercing the strata. The hollow centers of these concretions, also, are filled with bitumen, and vesicles in the concretion walls contain bitumen. Thin sections of specimens of the breccia and of the concretions show small annular casts which might be taken to represent *Globigerina*. *Globigerina* is found both in the Canguinsa and in the Vigo, so that the breccia might be portions of either of these formations so far as this evidence is concerned. Photographs of both the breccia domes and the concretions appear in Plate I.

The following analyses show in part the composition of a fragment from the breccia and of a piece of clay-tuff from the surrounding beds:

TABLE II.—*Analyses of breccia and of clay-tuff from Canguinsa clay-tuff: outcrop D, Butason River, Villaba, Leyte.*[a]

Constituent.	Clay-tuff.	Breccia.
Silica (SiO_2)	37.98	5.73
Alumina (Al_2O_3)	8.93	5.98
Ferric oxide (Fe_2O_3)	6.24	0.38
Ferrous oxide (FeO)	3.77	1.96
Calcium oxide (CaO)	17.56	28.80
Magnesium oxide (MgO)	3.80	13.80
Loss on ignition	21.56	43.22
Total	99.84	99.87

[a] Analyses by T. Dar Juan, chemist, Bureau of Science.

If the breccia rocks have been formed by the action of solutions on clay-tuff, the change has consisted principally in the addition of magnesium and calcium carbonates (especially magnesium carbonate) and the subtraction of silica. These results could be accomplished apparently by an alkaline solution, but it is not clear how the decrease in ferric iron could have been brought about by the same solution. The question of the origin of the breccias will require further study. Several mineral springs occur in northwestern Leyte, and analyses by the Bureau of Science of the waters from one of them, situated at Villahermosa, north of San Isidro, show an extremely high carbonic acid content with fair quantities of calcium, sodium, and magnesium.

The analysis of the clay-tuff at first sight does not bear out the conclusion that tuff is an important part of the rock. The silica-alumina ratio, however, is approximately the same as that of tuff in Cebu, which can be correlated stratigraphically with the Leyte clay-tuff, and the calcium, magnesium, and iron salts can be accounted for as additions from the sea water into which the tuff fell.

The total quantity of bitumen in sight at D is insignificant, but exploration might reveal a greater quantity and at the same time yield valuable information as to the origin of the bitumen deposits.

Outcrop D is in the general vicinity of the Mount Tabeyta intrusion, although at some distance (3 kilometers) from the peak itself. A clay-shale-breccia cemented by calcite and quartz, as has already been noted, was found on the summit of Mount Tabeyta. The suggestion may be put forward that the breccias and concretions at outcrop D are related to buried intrusions in their origin. The solutions which have impregnated the breccias and concretions might conceivably have been given off by an intrusion, but the manner in which the brecciation was accomplished without disturbing the surrounding clay-tuff beds is not clear. Although the Canguinsa clay-tuff is slightly petroliferous, there is certainly not enough bitumen in it to account for the concentration represented by the bitumen-cement in the breccias. Bitumen must, therefore, have been introduced into these broken rocks and solution channels, and the most reasonable assumption is that it ascended from a source in the underlying rocks—that is, from the Vigo shale.

Outcrops E, F, and G are pockets and irregular deposits of a solid, brownish black bitumen in Canguinsa clay-tuff. There are several other unmarked outcrops in the same region. The pockets follow bedding planes in the clay-tuff in a rough way, but also cross the beds irregularly and fill vertical openings in the formation. Several outcrops have been explored by short tunnels and by shafts, and a total quantity of perhaps 100 tons of bitumen has been recovered. The thickness of the deposits is rarely more than 1 meter, and some of them have failed laterally within distances of 10 meters. The openings are all filled with either débris or water, so that they afford little opportunity for the detailed examination of the deposits.

The bitumen has a schistose appearance and an irregular schistose fracture. Its specific gravity varies from 1.02 to 1.05, depending, perhaps, on the degree of freedom from inorganic impurities. The streak is brownish, somewhat lighter than the color of the bitumen itself. The deposits are at a higher horizon in the Canguinsa clay-tuff than the outcrops at D, and the attitude of the beds is again that at outcrops A and B: namely, strike, west-northwest; dip, 20° north-northeast.

At the point marked H on the map there is a petroleum seep in the Canguinsa tuff-sandstone. Except for the Mount Tabeyta intrusives only Canguinsa rocks are exposed in the neighborhood. The petroleum escapes in very small quantity from cracks and joints, but does not impregnate the rock itself. The strata appear to be about horizontal, but bedding planes are not clearly defined. The seepage is at the base of a hill barely above sea level. On the beach near by is a spring of mineralized water, which emits an odor of hydrogen sulphide. The attempt made during the Spanish régime to exploit the Leyte petroleum deposits centered at the seepage H. There is no evidence now that anything whatever was accomplished in these attempts.

The petroleum seep at I is in a stream bed which is deeply cut into the Vigo shale. The oil drips from the wall of the creek along the contact between the Vigo shale and diorite. The igneous rock appears to be a lens between beds of steeply dipping shale and from its position might be an intrusion. No evidence of disturbance or metamorphism is to be observed in the shale, however, and the igneous rock may be part of the base upon which the Vigo shale lies instead of an intrusion. On both sides of the diorite exposure, the width of which is a few meters only, the shale is very regular and dips to the north-northeast at an angle of 50°. To the north the Vigo shale is exposed continuously for a distance of at least 800 meters, maintaining always the same attitude. About 300 meters south of the seep the dip changes in direction to the south-southwest and decreases to about 30°, the strike remaining constant. Thus an anticline is indicated in the Vigo shale. Mount Camaro, in which the strata appear to be nearly horizontal, marks the crest of this fold, and the petroleum seeps I and J lie on the opposite limbs very near the axis.

The petroleum at the point marked J comes directly from the upturned edges of the Vigo shale. A pit about 2 meters deep was dug at J, and enough petroleum was encountered to make possible the collection of a 1-liter sample. Gas escaped from the floor of the pit with a slight rushing sound and moved small pieces of débris around which it flowed. The shale in the pit walls is dark in color and is impregnated with petroleum, although the flow of petroleum came from bedding planes and joints. Dark gray sandstone occurs in the shale, but while it has a strong petroliferous odor, it is not impregnated with petroleum. About 500 meters to the east of the seepage at J the Canguinsa rocks are encountered overlying the Vigo, but directly south of the seep the Vigo is exposed over a greater distance. The seepages at both I and J, therefore, come from beds which are well below the top of the Vigo shale. If the igneous rock at I is not intrusive, then the one seepage must be in the very base of the Vigo.

The petroleum at J is very fluid and has an odor of light oils. It is olive-green by reflected light and reddish brown by transmitted light. The results of fractional distillation appear in Table V under the discussion of the character of the petroleum and bitumens. Apparently the petroleum at H and I is of the same character as that at J.

At the point marked K there is a small outcrop of semisolid, black bitumen filling a pocket in loose limestone and clay. There are no good outcrops in the immediate vicinity, but it is probable that Vigo shale is the underlying rock. The outcrop is too small to afford any idea of the character of the bitumen or of the manner of its occurrence.

At L and M, near the town of Villaba, there is an apparently extensive deposit of solid bitumen mixed with fragments of Canguinsa clay-tuff. This material is encountered just beneath the surface and has been opened by shallow pits at two places about 300 meters apart. About 100 tons of the mixture have been mined from these openings, one of which reached a depth of 5 meters continuously in the bituminous material. The bitumen in this deposit is like that in the region of the E, F, and G outcrops in character, but within a few meters of the openings there are also domes or chimneys of brecciated, hardened clay-tuff cemented with viscous bitumen like the material in the outcrops at D. Outcrops L and M appear to be in the upper part of the Canguinsa clay-tuff, which in this vicinity dips at low angles to the south.

At the point marked N on the map in fig. 2 is the deposit of bituminous limestone already mentioned. At this place porous limestone and porous sandstone belonging to the Malumbang series have been saturated with a viscous, black bitumen. The Malumbang series is at least 50 meters thick here, and the beds dip gently to the south. The outcrop is a cliff 12 to 20 meters high, forming one wall of a cañon. The impregnation extends over a distance of at least 50 meters along the cañon floor. No exploration has been performed, and there is no evidence as to how far at right angles to the exposed face the impregnation may continue. The lower bituminous beds are sandstone made up of fine fragments of limestone, feldspar, glass, and quartz. The upper beds consist of a granular limestone which does not disintegrate upon the removal of the bituminous impregnation. Blocks of the bituminous material of many tons' weight have been broken off and carried down the cañon.

Across the cañon from the bituminous beds in the Malumbang series, exposures of Vigo shale were observed dipping at a high angle in a direction opposite to that in which the Malumbang dips. The relations suggest the presence of a fault in the vicinity, on one side of which the Vigo shale has been thrust up until it is in contact with the Malumbang on the opposite side.

On going down the cañon westward, Canguinsa clay-tuff is encountered beneath the Malumbang series, and in the floor of the cañon near the base of the Canguinsa one of the bitumen-filled cylindrical concretions, like those noted at outcrop D, was observed. At a distance of about 1 kilometer from the deposit, and at an elevation about 100 meters lower, Vigo shale appears beneath the Canguinsa. The Vigo in this position dips to the south at an angle of about 30° and is thus in conformity with the overlying rocks. A small outcrop of andesite occurs a few meters farther down the cañon toward Baliti; it is evidently an intrusion in the Vigo shale.

Near the barrio of Tabubunga, 10 kilometers south of Villaba and outside the area included in fig. 2, I saw a small quantity of a viscous, black oil seeping from joints in a thin bed of sandstone near the base of the Vigo shale. This seepage is somewhat more than 1 kilometer inland from Tabubunga along Tabubunga River, at an elevation of about 30 meters. In going to the seepage from Tabubunga, I crossed successively the Malumbang series, the Canguinsa clay-shale, and practically all of the Vigo shale almost to the contact of the latter with the basal complex upon which the sedimentaries lie. The dip is constantly seaward (west) at an angle of about 30° throughout each of the formations. Thus the sedimentary formations are much thinner at Tabubunga than they are at Villaba. The thickness of the Vigo shale especially has diminished in the section at Tabubunga, a condition which is due probably to the varying overlap of its beds on the basal rocks.

CHARACTER OF THE PETROLEUM AND RESIDUAL BITUMENS

Natural bitumens are generally conceded to have their origin in petroleum and to consist of various hydrocarbon residuals, left upon the evaporation or dissipation of the more volatile constituents of petroleum. Definite mineral names have been applied to a number of natural bitumens of different character, and this mineral classification is assumed to be complete. But in attempting to classify the various bitumens in Leyte as one or another of the recognized bitumen minerals, I find that the descriptions of none of the several types apply exactly. If the facts that petroleums vary widely in character and that the residuums from each petroleum form a continuous series from petroleum at one end to a metamorphic product similar to coal at the other end are considered, the difficulty of placing all the possible residual bitumens in a half-dozen classes will be apparent. Yet it is obviously not desirable to consider each natural bitumen as a distinct mineral species and to give it a separate name. Consequently I have applied only the broad term natural bitumen to the petroleum residuals in Leyte.

The following table contains data as to the physical properties of the three principal types of natural bitumens found in Leyte: namely, (1) the material from outcrops A and B; (2) material from outcrop D; and (3) material from outcrops E, F, and G. The bitumen in the mixture at L and M resembles that from E, F, and G, while the bituminous cement in the limestone and at N is similar to the material in outcrop D.

TABLE III.—*Physical properties of natural bitumens from Villaba, Leyte.*

Property.	Outcrop.		
	A and B.	D.	E, F, and G.
Specific gravity	1.05	1.016	0.98-1.02.
Hardness	2.00		1.5.
Color	Jet black	Black	Brownish black.
Streak	Black		Light brown.
Luster	Brilliant		Dull.
Structure	Columnar	Viscous	Schistose.
Fracture	Conchoidal		Irregular schistose.
Flows	Intumesces, softens, and flows imperfectly at 150° C.	At 35° C	At 75° C.

The Leyte natural bitumens are derived from a paraffin-base petroleum. This fact at once distinguishes them from asphalt, as most commonly defined, which is derived either naturally or artificially from petroleum with an asphaltic base. The natural bitumen from outcrops E, F, and G was classified at the time of its discovery as gilsonite (or uintahite, another name for the same mineral). But gilsonite is black and lustrous and breaks with a perfect conchoidal fracture. The material from this group of outcrops is dull brownish black and breaks with a schistose fracture. Its specific gravity and its hardness are both less than the corresponding figures for gilsonite. Moreover, gilsonite, according to Richardson,[7] who has devoted a great deal of study to this subject, is derived from a nonparaffin oil and is not soluble in paraffin residues. All the Leyte bitumens are paraffin-bearing and are, therefore, not gilsonite according to Richardson. The bitumen from outcrop B is more nearly like gilsonite in physical appearance, being brilliant black in color and conchoidal in fracture. Its streak, however, is black, while the streak of gilsonite is reddish brown, and it contains a large proportion of paraffin.

Grahamite, another natural bitumen, has something of the physical appearance of the bitumen from outcrops E, F, and G; Richardson states that it may be derived from paraffin petroleums. But grahamite is heavier than any of the Leyte bitumens and has a higher proportion of fixed carbon.

Ozocerite is defined as a native paraffin, the physical appearance of which varies. Its color may be the same as that of some of the Leyte bitumens, its specific gravity is somewhat less, and it probably contains a higher average proportion of paraffin.

The petroleum from Leyte is a light, fluid oil, olive-green by reflected light and reddish brown by transmitted light. Its character is shown by the fractionations recorded in the following tables. Table IV contains the analysis of a sample which was secured by Mr. William Anderson, of Tacloban, Leyte, from the seepage at I and had probably deteriorated by exposure.

TABLE IV.—*Distillation products of petroleum from seepage I, Villaba, Leyte.*[a]

Constituent.	Percentage by weight.
Gasoline (110° to 170° C.)	0.88
Kerosene (170° to 270° C.)	17.51
Heavy oils (270° to 315° C.)	19.91
Residue, pitch (above 315° C.)	61.70

[a] Analysis by A. S. Arguelles, chemist, Bureau of Science.

---

[7] *Journ. Am. Chem. Soc.* (1910), 2, 1032.

A sample which I collected from a shallow pit at seepage J, about fifteen hours after the pit was completed, yielded the following results upon distillation:

Table V.—*Distillation products from seepage J, Villaba, Leyte.*[a]

Constituent.	Percentage by weight.
Gasoline (0° to 150° C.)	5.4
Kerosene (150° to 300° C.)	33.7
Heavy oils (300° to 400° C.)	55.3
Residue, pitch (above 400° C.)	5.6

[a] Analysis by A. H. Wells, chemist, Bureau of Science.

This petroleum contains 8.14 per cent of paraffin. The specific gravity of the crude oil is 0.8597. Unfortunately the sample was too small to permit of specific gravity determinations on the individual fractions.

For purposes of comparison the following analyses of petroleums from Tayabas and from Cebu are quoted from the report on the Tayabas field.[8] Sample 1 was taken from a shallow well at Bahay, Tayabas, twenty-four hours after the well had been pumped dry. Sample 2 was taken from a well drilled at Toledo, Cebu, in 1896.

Table VI.—*Products of distillation of petroleum from Tayabas and Cebu.*

Constituent.	Sample 1.[a]		Sample 2.[b]	
	Specific gravity at 29° C.	Volume.	Specific gravity at 15° C.	Volume.
		Per. ct.		*Per. ct.*
Crude	0.8323		0.885	
Gasoline (below 150° C.)	0.7692	30.4	0.762	6.2
Kerosene (150 to 300° C.)	0.8333	50.9	0.832	42.32
Heavy oils (300° to 400° C.)[c]	0.9061	15.1	0.901	38.3
Residue (above 400° C.)[d]		3.6		13.17

[a] Analysis by E. R. Dovey, chemist, Bureau of Science. A determination on a separate sample of Tayabas petroleum yielded 8.1 per cent of paraffin.

[b] Analysis by H. C. Brill, chemist, Bureau of Science.

[c] Temperatures 300° to 375° C. for sample 2, heavy oils.

[d] Temperature above 375° C. for sample 2, residue.

It will be seen from the foregoing analyses that the Leyte petroleum is intermediate between the petroleum from Cebu and Tayabas in specific gravity and that all three petroleums contain high percentages of burning oils; all three oils, likewise, are high in paraffin.

---

[8] *This Journal, Sec. A* (1913), **8**, 358.

Determinations by Mr. Arguelles show that the lustrous black, solid material from the outcrop at B contains 94.53 per cent of bitumen soluble in carbon disulphide, 3.89 per cent of paraffin scale, and 26.62 per cent of fixed carbon. The specific gravity of the sample tested was 1.068. .The material cokes upon distillation.

Determinations by Mr. Arguelles on a sample of the sticky bitumen from the outcrop at D showed: Specific gravity, 1.016; total bitumen, 81.84 per cent; paraffin scale, 0.30 per cent; fixed carbon, 6.59 per cent. The penetration (test with No. 2 cambric needle for five seconds with 100 grams' weight) is 1.3 millimeters at 30° C. and 2.6 millimeters at 50° C. The softening point of this material is 35° C.

Determinations by Mr. Arguelles on the brownish black, solid bitumen from outcrops E, F, and G showed: Specific gravity, 1.026; penetration at 25° C., 0.6 millimeter; loss at 163° C. for five hours, 3.28 per cent; total bitumen, 93.79 per cent; organic insoluble constituents, 1.00 per cent; mineral matter, 5.21 per cent; paraffin, 11.05 per cent; fixed carbon, 7.68 per cent. The following table contains analyses of different samples of material from outcrops at E, F, and G. Sample 1 represents pure bitumen; sample 2, bitumen of poorer quality.

TABLE VII.—*Analyses of bitumens from outcrops E, F, and G, Villaba, Leyte.*[a]

Constituent.	Sample 1.	Sample 2.
	Per cent.	*Per cent.*
Moisture and loss at 100° C	0.56	2.80
Petrolene	63.45	26.26
Asphaltene	28.59	22.53
Organic nonbitumen	4.68	11.64
Mineral matter	2.88	36.78
Total	100.16	100.01

[a] Analyses by A. H. Wells, chemist, Bureau of Science.

In the mixture of bitumen and clay-tuff from outcrops L and M Mr. Arguelles found 25.12 per cent of total bitumen, 21.6 per cent of which is paraffin scale. Mr. Wells distilled from another sample of the mixture from these outcrops 17.46 per cent (material as received) of heavy oil, which he fractionated as follows:

TABLE VIII.—*Distillation products from heavy oil obtained from bituminous mixture at outcrops L and M, Villaba, Leyte.*

Constituent.	Per cent.
Gasoline (below 150° C.)	10.0
Kerosene (150° to 300° C.)	36.0
Heavy oils (300° to 400° C.)	52.0
Pitch residue (over 400° C.)	2.0

The rock asphalt at N varies considerably in its content of bitumen. Mr. Arguelles found in a sample from the lower beds 61.85 per cent of total bitumen, while two samples from the upper part of the deposit, examined by Mr. Wells, yielded 6.30 per cent and 8.84 per cent of the total bitumen, respectively. The sample richest in bitumen contained only 0.13 per cent of paraffin scale. The strikingly lower paraffin content of the bitumens from outcrops D and N as compared with the bitumens from the other outcrops may be due to the fact that the bitumens at D and N have migrated through porous or broken rocks, while elsewhere the bitumens have simply occupied open spaces in the rocks. That is to say, the paraffin might have been removed by the filtering effect of the diffusion of the original petroleum through porous rocks.

SOURCES AND PROBABLE QUANTITIES OF PETROLEUM AND RESIDUAL BITUMENS

The source of the residual bitumens in Leyte is undoubtedly the petroleum with which they are associated. Natural bitumens are universally conceded to have their origin in petroleum, being formed through the elimination of the more volatile constituents and the concentration and metamorphism of the heavier hydrocarbons. The bitumens in Leyte form so nearly a continuous series from petroleum to solid coallike bitumen and are so like the base of the Leyte petroleum in their constitution that the relation of one to the other would be clear without the necessity of drawing analogies from what has been learned concerning other natural bitumens.

The source of the petroleum in Leyte is probably the Vigo shale, just as the Vigo shale appears to be the source of the petroleum in the Tayabas field, where the essential conditions are similar to conditions in Leyte. Possibly some of the Leyte petroleum originates in the Canguinsa, although the fact that petroleum and residual bitumens are found in the Canguinsa at present may be explained otherwise. In all the observed occurrences of petroleum and residual bitumens in Leyte there is none which could not have originated through the infiltration of petroleum from the Vigo shale. Samples of *Globigerina*, which were found in the Vigo shale in Tayabas and were rather doubtfully credited with the origin of the Tayabas petroleum in the previously cited report on that field, occur abundantly in the Canguinsa as well as in the Vigo in Leyte. If these little animals are really the ultimate source of the petroleum, then the Canguinsa must have yielded more petroleum than the Vigo. But the truth of this theory is not established. Nowhere, as a matter of fact, has *Globigerina* been observed in numbers sufficient to justify the idea that it is the source of more than a very limited quantity of petroleum.

That petroleum is present in the Vigo shale in Leyte as well as in Tayabas and in Cebu is a matter of common observation. Evidence has been cited in the descriptions of several of the occurrences in Leyte which indicates that the petroleum moved through the Canguinsa clay-tuff along fractures, bedding planes, faults, brecciated zones, and open fissures, but nowhere is there evidence that the petroleum permeates the clay-tuff itself. It is certain that the Vigo shale is petroleum-bearing, and while the Canguinsa sandstone may also be a source of petroleum, it is not unreasonable to assume that most of the petroleum and residual bitumens now found in the Canguinsa migrated into that formation from the underlying Vigo shale.

The possible relation of the intrusive rocks to the accumulations of petroleum which gave rise to the deposits of natural bitumen should be taken into consideration. Outcrops L and M consist of breccias very like the breccia produced by the Mount Tabeyta intrusion. At outcrop D there are breccias and concretions which appear to be related to hidden intrusions. Intrusive rocks are found below the outcrops at N in the neighborhood of a probable fault plane. It is true that in the immediate vicinities of the largest intrusions no petroleum nor bitumen is encountered at the surface, but at distances of from 2 to 3 kilometers from the center of Mount Tabeyta, which is itself something like 1 kilometer in diameter at its base and over 200 meters high, are several important outcrops. The larger number of the intrusions found are in the Vigo shale and do not reach the overlying rocks, a fact which makes it probable that in territory covered by the upper rocks, like the vicinities of most of the bitumen outcrops, other intrusions exist beneath the surface. The suggestion may be made, therefore, that the intrusions have driven petroleum from the beds penetrated—Vigo shale and possibly also Canguinsa clay-tuff—into the fractured and brecciated zones resulting from the intrusions.

There is no way of ascertaining what quantity of petroleum may be obtained from a petroleum field except by the actual drilling of wells, and speculation in advance of all exploration can have little value as an estimate. In the study of the Tayabas field it was observed that petroleum reached the surface near the top of the Vigo shale only, in a series of close-grained beds from 50 to 100 meters in thickness, and the inference was clear that if the petroleum were confined to these beds in which it appeared at the surface there could be little hope of a quantity of petroleum comparable with the yields of the larger fields in America. In other words, the porous beds necessary to serve as reservoirs for large petroleum accumulations are not extensive or, at any rate, not prominent, in Tayabas.

In Leyte the situation is similar, although petroleum appears to be present at horizons lower in the Vigo shale than are the seepages in Tayabas, and the quantity of petroleum represented by the various deposits of residual bitumens is much greater than there is direct evidence of in the surface indications in Tayabas. But the petroleum from which the bitumen deposits in Leyte are derived may have been driven from the petroleum-bearing rocks by the action of heat from intrusions, a process which would have removed petroleum from the Vigo shale or the Canguinsa clay-tuff very efficiently. Similar intrusions in the Vigo shale in Tayabas might have caused equally extensive surface showings. If the possible agency of intrusions in the concentration in Leyte of quantities of residual bitumens great enough to demonstrate the former presence of large volumes of petroleum be admitted, the presence of these bitumens does not prove that drilling would result in the recovery of equally large volumes of petroleum, even though the major part of the original supply is still held in the rocks. Drill holes simply permit the flow of petroleum and are most effective when they penetrate saturated, porous beds, while intrusions would have forced the petroleum out of the adjacent beds—porous or close-grained, saturated or only partly saturated.

It is improbable that wells drilled into the close-grained Vigo shale either in Leyte or in Tayabas will yield the large flows obtained in other fields from extensive lenses of porous sandstone. There is in Leyte, however, the chance that pockets of petroleum in the broken zone surrounding an intrusion (assuming that the intrusions have in reality been effective in concentrating the petroleum) may have been preserved by the sealing up of passages through the overlying beds, and wells penetrating such zones might obtain larger flows than the undisturbed shale would yield.

The deposits of solid bitumens indicate the former presence of a large quantity of petroleum in the Leyte formations. But they indicate also the escape and consequent loss of much of the original supply. Just what proportion may remain is undetermined. When all is said and done, definite evidence as to the quantity of petroleum present in Leyte and in Tayabas will be obtained only by drilling test wells.

The evidence as to the quantity of solid bitumens present in Leyte is somewhat more definite, but here again lack of exploration makes impossible the exact estimates that are desirable.

The tonnage of deposits like those outcropping at A and B cannot be estimated in advance of exploration. The width of the fissure or vein at B as revealed in the floor of the shallow pit opened there is about 60 centimeters. The gilsonite veins in Utah, according to George H. Eldridge,[9] range in width from 45 centimeters to over 5 meters and contain a total quantity of more than 30,000,000 tons. While the vein at outcrop A in Leyte is thin, its width is of the same order of magnitude as the width of the veins in Utah. In Utah, however, the outcrops even of the small veins can be traced for several kilometers, while the vein at outcrop A can be followed a few meters only on the surface. Yet the vein at A may be found to be persistent underground, for it is well known that outcrops are usually obscure in the Philippines. The outcrop of the coal bed mined at East Batan, Albay, for instance, could be traced on the surface only a comparatively short distance, yet the workings in the mine ultimately proved an area of 50 or more hectares with the coal always regular and continuous. Only by exploration can the extent of the vein at B be ascertained. Without exploration there is in sight at the present time only a few tons of bitumen.

At C and D the quantity of bitumen in sight is insignificant, but no prospecting of the outcrops has been attempted.

Limited exploration on several outcrops in the region of E, F, and G has recovered only 100 tons or so of bitumen and has indicated that some of the deposits contain not much more than this quantity of material. The work has been only superficial, however, and it may be possible to follow the irregular bodies beneath the surface into deposits of larger proportions.

The outcrop at K has not been explored, but the surface indications promise little in the way of tonnage.

[9] *22d Annual Rept. U. S. Geol. Surv.* (1900–1901), pt. 1, 342 et seq.

The work on the outcrops at M and N has been too limited to prove the extent of the deposit. About 100 tons of the mixture of bitumen and clay-tuff has been mined. The surface conditions indicate a considerably larger deposit in this vicinity than in any of the foregoing. The thickness is greater, and outcrops are found over an area of fair dimensions. It is claimed by interested prospectors that exploration by drilling has proved a thickness of about 15 meters over an area 300 meters square. It is stated also that the same bituminous mixture is encountered beneath the surface in the town of Villaba at a distance of 800 meters north of the outcrop at L. The exploration of the deposits at L and M would be a simple and inexpensive undertaking, since the breccia of bitumen and clay-tuff appears to lie near the surface.

The quantity of rock asphalt at N undoubtedly is to be measured in thousands of tons. Although no exploration has been undertaken, the dimensions of the exposed face make it certain that there are present at least several thousand tons. If the vertical dimensions of the deposit and its dimensions at right angles to the exposed face are of the same order of magnitude as the revealed length of the face—suppositions which are by no means unreasonable—the total quantity of rock asphalt at N must amount to hundreds of thousands of tons.

THE UTILIZATION OF THE RESIDUAL BITUMENS

If petroleum is obtained commercially in Leyte, no problem arises as to its disposal. The Philippine market for petroleum products amounted to 3,641,078 pesos[10] in 1914, according to the import records of the Collector of Customs as shown in the following table:

TABLE IX.—*Imports of petroleum products into the Philippine Islands in 1914.*

Petroleum product.	Quantity.	Value.
	Liters.	*Pesos.*
Crude oil, including all natural oils without regard to specific gravity	1,689,108	48,360
Refined or manufactured oil, naphtha, including all lighter products of distillation	5,508,189	563,408
Illuminating oil	48,517,689	2,562,040
Lubricating and heavy paraffin oil	3,048,610	426,258
Residuum, including tar, and all others, from which the light bodies have been distilled	765,182	41,012
Total	59,528,778	3,641,078

---

[10] One peso Philippine currency equals 100 centavos, equals 50 cents United States currency.

If petroleum were available in quantity at a cost which would make it a competitor with imported coal as fuel, the present Philippine petroleum consumption would be multiplied. Inter-island steamships and the railroads would undoubtedly adopt oil fuel, and these factors alone would greatly increase the market for petroleum.

With the residual bitumens, however, the case is different. The rock asphalt from the deposit at N may prove valuable as a paving material. Two representative samples of the rock asphalt yielded 6.30 and 8.84 per cent of bitumen, respectively. A sample from the rich lower portion of the deposit contained 61.85 per cent of bitumen. Probably the average grade of material carries from 6 to 10 per cent of bitumen. The rock asphalt most widely used in Europe carries from 6 to 8 per cent of bitumen. Other rock asphalts carry from 10 to 12 per cent of bitumen, but are mixed with poorer materials for use. It is stated that a rock-asphalt pavement should contain from 7 to 10 per cent of bitumen.

One of the principal objections to rock asphalts has been the contention that the bitumen is usually insufficiently asphaltic in character to make a good binder in pavements. In the following table are analyses of the rock asphalt from the outcrop at N compared with analyses of sheet-asphalt pavement and with analyses of rock asphalts from Oklahoma, which have been proved to be of superior quality for paving:

TABLE X.—*Analyses of rock asphalts and sheet asphalts.*[a]

Source.	Total bitumen.	Petroleum.	Asphaltene.
	Per cent.	*Per cent.*	*Per cent.*
Outcrop N, Villaba, Leyte	8.84	56.0	44.0
	6.30	58.0	42.0
Sheet-asphalt pavement:	13.5	90.1	9.9
Muskogee	9.1	67.1	32.9
Oklahoma	11.0	78.1	21.9
Rock-asphalt pavements in Oklahoma	7.85	78.81	21.19
	10.10	72.65	27.35
	9.80	70.61	29.39

[a] First analyses by A. H. Wells, chemist, Bureau of Science. Other analyses are from Oklahoma Geological Survey Circular 5 (1913), 18.

The Leyte rock asphalt has more asphaltic constituents than the rock asphalt from Oklahoma, which is a superior paving material. Consequently no insufficiency of asphaltic compounds can be charged against the Leyte rock asphalt. It is even possible that it is too high in asphaltic constituents and will demand fluxing with petroleum residuum as do the true asphalts. Paraffin, an ingredient which must be low in paving asphalts, and is objectionably high in some of the Leyte bitumens, is remarkably low in the Leyte rock asphalt, amounting to less than 0.5 per cent of the bitumen present. Thus the laboratory investigation of samples of the Leyte rock asphalt indicate that it could be used for paving. But the question is one which cannot be definitely answered except by actually laying an experimental pavement and observing its behavior under traffic.

If the rock asphalt proves to be a good paving material, there would be a market for it in the paving of city streets and important roads in the Philippines. The cost of quarrying the rock asphalt and bringing it to deep water should be small. The scarcity of really superior stone for macadam and the cost of the asphalt pavements which have already been laid in the Philippines make it appear that a suitable rock asphalt could be transported from Leyte to Manila and elsewhere at a profit to the quarry enterprise and with a saving in the cost of asphalt pavements. Consul-General George E. Anderson, at Hongkong, believes[11] that there is a possible market for asphaltic paving materials in oriental cities outside the Philippines. Such a demand might mean the profitable exportation of the Leyte rock asphalt.

Rock-asphalt pavements have been employed extensively in Europe, especially in France and Italy. In the latter country the production from 1904 to 1912 ranged between 108,000 and 191,000 metric tons, valued at an average of about 6 pesos per ton. In the United States rock-asphalt pavements have found less favor than in Europe, partly, at least, because of the cheapness of artificial asphalt from petroleum. Oklahoma rock asphalt is coming into use, however, and even in California, where artificial asphalt obtained from petroleum is abundant, 27,600 metric tons of rock asphalt, valued at 6.18 pesos per ton, were mined in 1913.[12]

Rock asphalt in pavements is laid like sheet asphalt. A concrete foundation is generally employed, and the rock asphalt, pulverized to maximum diameters of 1 centimeter, is heated to about 150° C. (considerably less than the temperature required for sheet asphalt), spread on the foundation with rakes, and rolled while hot. The wearing coat is about 5 centimeters thick after rolling.

---

[11] Daily Consular and Trade Report, June 9 (1914).

[12] Data taken from *Min. Resources U. S. Geol. Surv.* (1913), pt. 2, 539.

Both the physical characters and the chemical compositions of the other residual bitumens make them unfit for use in pavements. Materials of similar character are widely used in America and Europe for other purposes, however, and are more valuable than paving asphalt. The utilization of these bitumens in the Philippines is complicated by the restricted local market for the products made from them elsewhere. Their exploitation, therefore, if they are developed in quantity, must be preceded by the establishment of a market either locally or through exportation. The purposes for which they can best be utilized is a subject for chemical investigation, but the following list of possible uses for gilsonite and related asphaltic substances may be quoted:[13]

> The manufacture of black, low-grade brush and dipping varnishes, such, for instance, as are used on the various kinds of ironwork, and as baking japans; * * * for preventing electrolytic action on iron plates of ship bottoms; for coating barbed-wire fencing, etc.; for coating sea walls of brick or masonry; for covering paving brick; for acid-proof lining for chemical tanks; for roofing pitch; for insulating electric wires; for smoke-stack paint; for lubricants for heavy machinery; for preserving iron pipes from corrosion and acids; for coating poles, posts, and ties; for toredo-proof pile coating; for covering wood-block paving; as a substitute for rubber in the manufacture of cotton garden hose; as a binder pitch for culm in making brickette and eggette coal.

Some of these possible products would find no market locally, and chemical investigation may prove the Leyte bitumens unsuited for the manufacture of many of them, but it would also undoubtedly reveal other uses to which they might be put. The analyses already performed show that some of the bitumens are high in paraffin, a substance which is used locally in the manufacture of matches and candles and which could probably be exported at a profit, since it is worth in the crude state about 34 centavos per kilogram.

Another possible use for the Leyte bitumens and bituminous mixtures is suggested by the exploitation of the so-called kerosene shales in Scotland and in New South Wales. The Scotch shales yield upon distillation about 96 liters of crude oil per metric ton. The crude oil, upon fractionation, yields in turn 6 per cent of gasoline, 32 per cent of kerosene, 24 per cent of heavy oils, and 12 per cent of paraffin scale.[14] According to the distillation tests quoted on another page, 1 ton of the mixture of bitumen and clay-tuff from outcrops L and M yields about 175 liters of crude oil containing 10 per cent of gasoline, 36 per cent of kerosene, and 52 per cent of heavy oils. The heavy oils and residue contain about 20 per cent of paraffin. Therefore the mixture from outcrops L and M yields nearly twice the volume of oil that the Scotch shales yield, and the oil obtained contains a higher proportion of the lighter, more valuable constituents. From the best shale in New South Wales more than 600 liters of crude oil per ton are obtained, but the average yield is much less than this figure. It might be found practicable to enrich the bitumen mixture from outcrops L and M in Leyte by additions of the pure bitumens from the other outcrops and so obtain more crude oil upon distillation. The distillation products from the rock asphalt at N are similar in character to those from the mixture at L and M, and although most of the rock asphalt contains too little bitumen to justify distillation, parts of it are much richer than the mixture from L and M. One sample from N, for instance, yielded almost 62 per cent of bitumen. Gasoline, kerosene, and heavy oils, whatever their source, would find a ready market in the Philippines.

---

[13] Eldridge, G. H., op. cit., 356.

[14] Lewes, Vivian B., Liquid and Gaseous Fuels. Archibald Constable & Co., Ltd., London (1907), 97.

It is concluded, then, that the natural bitumens in Leyte can be profitably utilized if they are developed in quantity.

SUGGESTIONS FOR EXPLORATION

The possibility of obtaining petroleum commercially in Leyte should be investigated further. My observations do not enable me to indicate the most favorable drilling sites nor even to state that the chances of success are great enough to warrant drilling. The venture might not prove attractive to private capital, but considering the immense industrial importance of petroleum to the Philippines, the Government might be justified in an attempt at development.

This recommendation that the Government undertake to explore petroleum deposits has already been made in the case of the Tayabas field. In view of the later investigation of the Leyte region a question arises as to which territory offers the better chance of success, which should be explored first, and whether or not both fields should be tested. The answers to these questions must await further geologic study.

It may be explained that petroleum is commonly found in porous beds, where it is retained by cover and floor of close-grained impervious beds after having been driven to the highest points to which it has access by the buoying-up effect of the heavier, associated water. Differences in the elevation of a given bed are usually due to folding, and thus it is that petroleum has so often been encountered in the arches or anticlines of folds as to give rise to the term "anticlinal theory" to designate this interpretation of the principles of petroleum accumulation. Many other causes, of course, may result in the entrapping of petroleum in the higher portions of porous beds: for example, a dike of impervious rock may cut through beds tilted in one direction and confine petroleum migrating through the porous bed from below; or the same thing may be accomplished by the sealing of the pores at the surface of tilted beds by the residuum left from escaping petroleum so that the rest of the petroleum is retained. In its widest sense the anticlinal theory accounts for the petroleum accumulations in a majority of the productive petroleum fields.

Petroleum seepages occur along the anticlines both in Tayabas and in Leyte, indicating that the anticlines are points of accumulation in these fields as they are in Sumatra and Japan, in which countries large commercial productions are obtained from formations of the same age and general character as the Philippine petroleum-bearing rocks.

Intrusive rocks are generally considered as an unfavorable indication in connection with prospective petroleum fields, for the reason that by their intrusion these rocks break up and shatter the strata which they penetrate, destroying the original structure and permitting the escape of any accumulated petroleum. However, the history of the development of parts of the Mexican petroleum field, which has recently attained an enormous production, shows that in this one instance intrusive rocks have not been injurious, but have actually accomplished the concentration of the petroleum, displacing it from buried strata and providing a reservoir for its accumulation in the openings of the shattered zone surrounding the intrusion. Intrusions have become centers of accumulations, seepages occur near intrusions, and wells drilled in the vicinity of an intrusion have repeatedly been successful.

In determining whether drilling in Leyte is warranted and, if so, where test wells should be located, data should be sought which will tend to show whether the igneous intrusions have merely dissipated the petroleum or have also promoted the accumulation of petroleum under favorable circumstances; whether there are accumulations of petroleum in structurally favorable areas independent of the intrusions; or whether both these factors are effective in controlling the accumulation. To determine these points, a detailed geologic study should be made both in the vicinities of anticlinal structures and in the vicinities of intrusions in Leyte.

It appears from the preliminary study that anticlines across the crest of which the rocks above the Vigo shale remain in place—that is, have not been eroded—are more promising than the anticlines upon the limbs of which the Vigo shale is exposed. The anticline at outcrop D, for instance, has afforded less chance for the escape of accumulated petroleum because of the presence of a cover of Canguinsa clay-tuff across its crest than the anticline at I and J, where the upturned edges of the Vigo are exposed at the surface. The anticline between I and J must be considered with still less promise, if the igneous exposure at I proves to be a part of the base upon which the Vigo lies. Nevertheless the large exposure of Vigo shale lying to the east and south of Villaba should be gone over in detail, particular search being made for seepages, intrusions, porous beds, and faults.

The region between outcrop N and the barrio of Baliti, where both intrusions and anticlinal structure are indicated, should be studied. The regions inland from the several coastal indentations between Villaba and San Isidro should be prospected. Seepages of petroleum and outcrops of solid bitumen other than those already discovered probably exist, and fixing the position of such occurrences will facilitate geologic interpretation.

If petroleum has accumulated in anticlines independently of intrusions, the northern part of the peninsula of northwestern Leyte, where folds undoubtedly exist in which the petroleum-bearing rocks are protected by a splendid cover of Canguinsa and Malumbang strata, should include promising territory. This area, therefore, should receive careful attention.

If the petroleum accumulations prove to be related invariably to intrusive rocks, the territory surrounding the intrusions will be most valuable. The known intrusions should be examined in the light of this suggestion, and search should be made for other intrusions.

In prospecting for other deposits of solid bitumens, the area south of Campocpoc is most promising, including territory as yet unexplored between Villaba and Tabubunga. No solid bitumens have been found in the Vigo shale; accordingly search for these materials should be directed especially to the upper rocks, although with only the data in hand at present it would be unwise to disregard the Vigo shale entirely. The solid bitumens, if not the petroleum, appear to be confined to regions where dynamic action has been comparatively severe, resulting in sharp folding, faulting, or intrusion. On the basis of this observation the foregoing recommendation of the southern part of the field is made.

Where petroleum-bearing rocks are exposed at the surface, as they are at I and J, shallow dug wells might be made to yield a small quantity of petroleum. Initial production in Japan and in Formosa came from dug wells. At any rate claim holders who lack capital for drilling might dig wells in this manner to answer the requirements for assessment work. Similar excavations on outcrops of semiliquid bitumen like those at D might also develop small flows of petroleum.

In exploring the deposits of solid bitumens, hand drilling should prove serviceable as supplementary to pits and tunnels. Drilling alone would be unreliable in deposits of bitumen mixed with clay-tuff like those at L and M. In tracing float bitumen to the original vein or deposit in place, open trenching might well be resorted to. Outcrops are obscure, and once a vein is found, it should be followed closely by excavation. The presence of faults may complicate the work of exploration.

SUMMARY

Several seepages of petroleum and a number of outcrops of residual bitumens derived from petroleum occur in the region of Villaba, Leyte, in easily accessible country. The containing rocks are of Tertiary and Quarternary age. The principal known occurrences are confined to an area 8 kilometers wide and 13 kilometers long. The petroleum appears to come from the Vigo shale, which belongs to the lower Miocene or Oligocene, while most of the residual bitumens are encountered in the Canguinsa clay-tuff, immediately overlying the Vigo. The various formations can be correlated perfectly with the rocks in which petroleum is found in Tayabas Province, and the two fields are very similar. Petroleum is obtained commercially from the same geologic horizon and from the same class of rocks in Sumatra, Formosa, and Japan. The total thickness of the bedded rocks is probably about 2,000 meters, and the petroleum comes to the surface at a horizon above the middle of the rock series.

The region of the outcrops and seepages in Leyte is sharply folded, and the lower strata, including those which are petroleum-bearing, are intruded by small bodies of andesite, some of which are domelike in shape. The distribution of the accumulations of petroleum and of bitumens derived from petroleum appears to be governed partly by anticlinal structure and partly by the intrusions. The petroleum has a paraffin base and a large proportion of burning oils. The different bitumens are semiliquid, viscous, and solid and cannot readily be classed according to the recognized mineral types. They all contain paraffin and are clearly derived from the associated petroleum. They are found filling fissures along bedding planes and in pockets, impregnating porous limestone and sandstones, in mixture with fragments of unchanged clay-tuff near the present surface, as cements in breccias of mineral-impregnated clay-tuff or shale, and in cavities in concretions in the clay-tuff. The pure bitumens cannot be used for paving purposes, but would be valuable in the manufacture of other products. One large deposit of bituminous limestone, or rock asphalt, has been found which can probably be used as a paving material. Some of the deposits of bitumens appear to be of limited size, but others are very probably large enough to be of commercial importance.

No exploration has been carried on in Leyte, but there is enough chance of obtaining petroleum to justify a thorough geologic study and probably enough chance to justify drilling at favorable sites. The least-promising feature of the field from this point of view is the apparent lack of porous beds adequate in extent to serve as reservoirs for large accumulations of petroleum, but there are many thin beds of sandstones intercalated with the Vigo shale, and further study may prove the aggregate volume of pore space in these beds to be large enough to afford abundant storage capacity.

ILLUSTRATIONS

PLATE I

(Photographs by Pratt.)

FIG. 1. Cylindrical concretion with bitumen-filled central opening protruding from Canguinsa clay-tuff. Campocpoc, Villaba, Leyte.

2. Bitumen-cemented breccia dome protruding from Canguinsa clay-tuff. Campocpoc, Villaba, Leyte.

3. Outcrop M, Villaba, Leyte. Mixture of bitumen and clay-tuff in Canguinsa clay-tuff.

4. Outcrop of petroliferous Vigo shale near Baliti, Villaba, Leyte; fissile beds dipping at an angle of about 30°.

TEXT FIGURES

FIG. 1. Outline map of northwestern Leyte.

2. Map of the vicinity of Villaba, Leyte, showing the situations of outcrops of bitumen and seepages of petroleum.

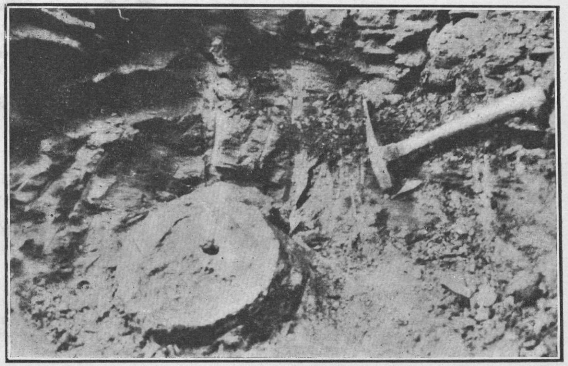

Fig. 1. Cylindrical concretion.

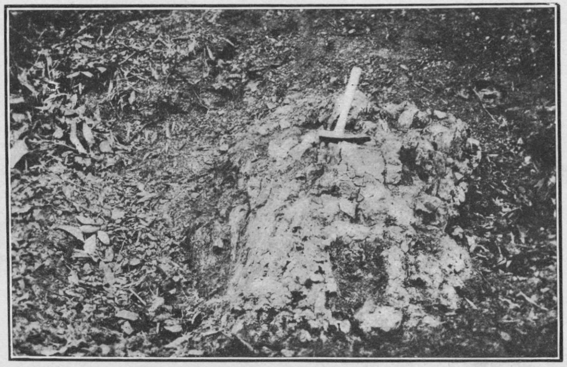

Fig. 2. Bitumen-cemented breccia dome.

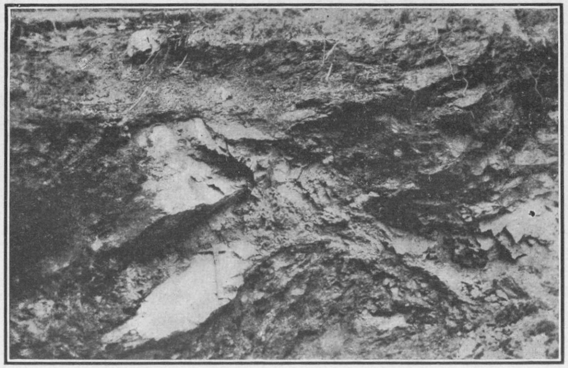

Fig. 3. Outcrop of bitumen.

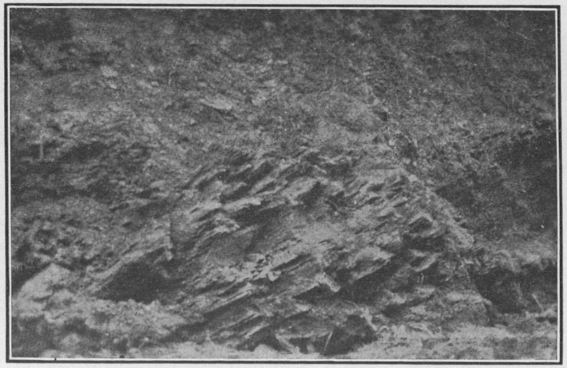

Fig. 4. Outcrop of Vigo shale.

PLATE I.

ON THE OCCURRENCE OF PETROLEUM IN THE PROVINCE OF CEBU[1]

By WALLACE E. PRATT

(*From the Division of Mines, Bureau of Science, Manila, P. I.*)

TWO TEXT FIGURES

HISTORICAL

The occurrence of petroleum in Cebu appears to have been first noted by the Spaniards about the year 1888. La Isla de Cebu,[2] a detailed geologic study by Abella, published in 1886, contains no reference to petroleum, but the same writer in La Isla de Panay,[3] published in 1890, in discussing a natural flow of inflammable gas which he encountered in Iloilo Province, states that shales which yield small quantities of petroleum had recently been discovered in Cebu.

The records of the Spanish inspectorate of mines show that application for the exclusive right to recover crude petroleum and to refine the same in the Philippines was made in 1893 by an Englishman, named Alfred White, who stated that he had discovered petroleum at Toledo, in Cebu, and that he wished to exploit other petroleum deposits on Negros and Leyte.

Becker[4] notes that petroleum is found at Asturias, Toledo, and at Alegria, on the west coast of Cebu, and refers to the Guia Oficial for 1898. Smith[5] visited Toledo and Alegria in 1906 and examined the petroleum prospects at these places. The observations which are embodied in the following notes were made recently during a number of short visits to Cebu for the examination of other mineral resources.

PETROLIFEROUS SHALE

A fine-grained, bluish gray shale, or clay-shale, which emits a slight odor of light oils and appears to be slightly petroliferous, is to be observed at widely separated places in Cebu and is probably of general distribution. This shale is exposed usually

---

[1] Received for publication April 23, 1915.

[2] D. Enrique Abella y Casariego, Rapida Descripcion de la Isla de Cebu. Madrid (1886).

[3] Descripcion de la Isla de Panay. Manila (1890), 125.

[4] Geology of the Philippine Islands, *U. S. Geol. Surv.* (1901), 107.

[5] *Far Eastern Rev.* (1907), 3, 9.

along streams, in steep walls to 10 meters high, with a massive or imperfectly bedded appearance. It is compact and fairly hard, breaking with a distinct conchoidal fracture and rarely parting along bedding planes. It occurs near the top of the coal-bearing rocks (Miocene) above the coal beds and the sandy shales and clastic rocks which constitute the greater part of the series, but below the uppermost limestone. This shale, which is conspicuous at Uling in central Cebu, and is found on Inayangan River in east-central Cebu and on Argao River in southeastern Cebu, may have been noted by Abella. From the results of distillation tests on similar shales from Tayabas Province it may be inferred that the petroleum content of this shale is too small to be of economic importance. It is more probable that the petroleum originated from organic matter in the shale itself than that it migrated to this shale from elsewhere.

PETROLEUM AT ASTURIAS

During a visit to Asturias in 1912 I was unable to obtain any information as to the existence of petroleum in that vicinity. No concession for petroleum at Asturias has been recorded. The only statement to be found in the literature is the reference by Becker to the Guia Oficial, which simply affirms that petroleum is found at Asturias.

PETROLEUM AT TOLEDO

On Calamanpao River near Iligan, a barrio of Toledo, are two oil wells, over one of which a steel derrick stands. Near by are a number of lengths of steel casings, parts of a horizontal engine, and a badly rusted boiler. The elevation at the wells is about 40 meters. A concession of 30 hectares was recorded for this locality in 1897 in the name of Cornelio Roberto Blair Pickford. This claim later came into the possession of Smith, Bell & Co., Limited, of Manila, who drilled the wells and control the property at present. Near the wells are pools of water, the surface of which is covered with oil. This film of oil suggests the presence of oil springs, but may be no more than seepage from the wells.

According to Smith[6] the wells were drilled in the year 1896 and reached a depth of 244 and 344 meters, respectively, operations having been interrupted by an insurrection. The wells have been partly filled with bamboo poles, and at present the casings are open for a few meters only below the surface. The well over which the derrick stands is evidently the deeper of the two. Three strings of casing, 12 inches (30 centimeters), 8 inches (20 centimeters), and 6 inches (15 centimeters) in diameter, respectively, are visible at the collar. Petroleum stands in the well at a level but little lower than that of the ground surface. The petroleum is buoyed up by a column of water below it, and probably fills only a short length of the casing, but enough is present to permit the collection of a dozen or more liters at any time. The other well, 50 meters distant, is cased with 8-inch (20-centimeter) pipe and yields oil in a similar manner and quantity.

---

[6] Loc. cit.

A sample of petroleum was collected from one of these wells in 1913 and brought to Manila for testing. Mr. F. R. Ycasiano, assistant engineer of the Bureau of Science, conducted 4-hour test runs with a Diesel motor, using the Toledo, Cebu, and Borneo crude oils in alternate tests. The Cebu oil proved to be a highly desirable fuel and somewhat superior to the Borneo oil.

Table I shows the specific gravities and percentage yields of the distillation products from Toledo, Cebu, crude petroleum.

TABLE I.—*Distillation products from Toledo, Cebu, crude petroleum.*[a]

Product.	Specific gravity at 15° C.	Volume.	Distillation temperature.
		Per cent.	°*C.*
Crude	0.885		
Gasoline	0.762	6.2	to 150
Kerosene	0.832	42.32	150–300
Heavy oils	0.901	38.3	300–375
Residue		13.17	375

[a] Analysis by H. C. Brill, chemist, Bureau of Science.

The foregoing analysis shows a much heavier oil than the product obtained from the Bondoc Peninsula field in Tayabas Province, which yields more than 40 per cent of gasoline.

The geologic structure at the site of the Toledo wells is monoclinal as shown in fig. 1. The beds lie upon the flank of the older igneous complex, which forms the core of the island. The rocks which outcrop at the wells are sandy shales, fine-grained clastics, and sandstones overlying sandy conglomerates, with a general dip to the northwest at an angle of from 50° to 60°.

A volcanic tuff outcrops just north of the wells on Calamanpao River and lies stratigraphically above the position of the wells in apparent conformity with the lower strata. It is a fine-grained, spongy, white rock, which breaks with a conchoidal or porcelanic fracture and is composed largely of minute fragments of volcanic glass. In its extension to the southwest the lower beds of the tuff grade into an increasingly coarse-grained volcanic agglomerate or breccia. A prominent hill, about 1.5 kilometers west-southwest of the oil wells and stratigraphically above (?) the beds which the wells pierce, consists of this agglomerate, the fragments in which are porphyritic andesite.

Overlying the tuff is the coralline limestone which fringes the entire Island of Cebu. In this locality it is 100 meters or more thick, consists principally of unconsolidated, imperfectly bedded coralline material, and dips about 35° northwest. Abella considered this limestone to be of Post-Pliocene age.

Below the horizon at which the wells are located the strata include coarse sandstones, sandy shales, clastics, and limestone, in the order named from the position of the wells to the igneous basement. These beds have the same strikes but dip somewhat more steeply than those at the well site. The whole thickness of sedimentary strata on this flank of the cordillera appears to be at least 2,000 meters, the oil wells occupying a position near the middle of the series. There are no beds in this series which are conspicuously petroliferous, but some of the sandstones near the oil wells emit an odor of petroleum.

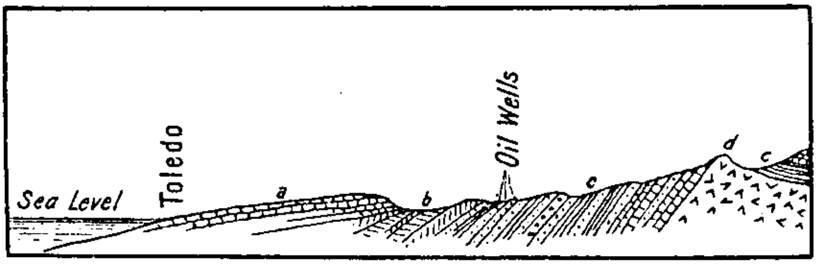

FIG. 1. Geologic section across strike of beds at Toledo, Cebu; partly diagrammatic. *a*, coralline limestone; *b*, tuff and agglomerate; *c*, Miocene shales, sandstones, conglomerates, and limestones; *d*, basal igneous complex.

The oil wells must have pierced the petroliferous sandstones close to their outcrop. A well drilled to the northwest of the old site would encounter these sandstones under cover and should prove whether or not petroleum can be obtained from them in large quantities. It would be expected that any but a viscous oil would be dissipated from the open edges of the strata in a monocline dipping as steeply as do the beds at this point. All the rocks in the vicinity of Toledo which appear to offer any chance of yielding petroleum could be tested by drilling a series of, say, three 600-meter wells along a northwest-southeast line across the strike of the beds.

PETROLEUM AT ALEGRIA

A fairly strong petroleum seep exists at the head of Malbog Creek near the town of Alegria. As early as 1897 a concession was recorded in the name of Smith, Bell & Co., Limited, for a petroleum claim of 150,000 square meters at Talayong, Alegria, and it appears that this claim covers the petroleum seep on Malbog Creek.

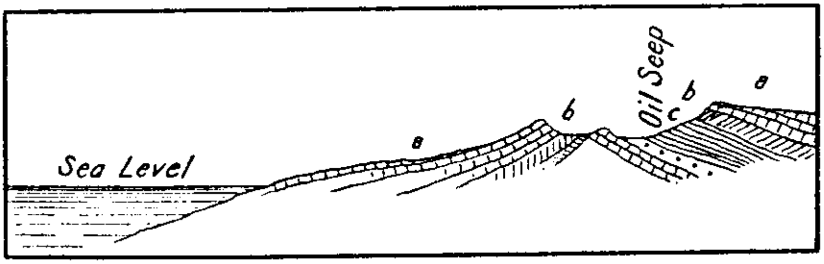

FIG. 2. Geologic section across strike of beds along Malbog Creek, Alegria, Cebu. *a*, coralline limestone; *b*, volcanic tuff; *c*, Miocene shales and sandstones over limestone.

Alegria is on the western coast of southern Cebu, and the mouth of Malbog Creek is about 2 kilometers north of the town. The seep is at an elevation of about 365 meters and is about 2.5 kilometers from the coast. Southern Cebu generally is covered with the recent coralline limestone beds; only in small areas are the underlying rocks exposed. Fig. 2 represents a section across the strike of the beds and shows the rock succession and structure at the head of Malbog Creek. The petroleum reaches the surface through beds of blue clay or shale and is identical in appearance with the Toledo oil. The oil seeps directly from blue clayey shale in the wall of a ravine, and there is usually a small pool of oil and water at the seep. Blue shale, brown sandy shales, sandstones, and soft light-colored tuff are exposed near the seep with a thickness of about 100 meters beneath a capping of perhaps 150 meters of coralline limestone. The tuff is less conspicuous than at Toledo. The general strike is north 20° east; and an anticlinal fold is indicated by the dips. In the crest and eastern limb of this fold the beds are standing on edge and appear to be considerably broken up. The first limestone outcrop to the west of the oil seep appears to dip to the east, and must, therefore, pass beneath the shale from which the oil seeps. The presence of a similar limestone at this horizon was not detected at Toledo. Placing this limestone in the eastern limb of the fold implies faulting in the plane of the anticlinal axis with an accompanying elevation of the eastern limb.

The petroleum seep at Malbog appears to be at a higher stratigraphic position than the oil encountered by the wells at Toledo; possibly, therefore, petroleum-bearing rocks at Malbog exist, a horizon lower than the seep, and petroleum migrates upward through the broken strata in the crest of the anticline.

The possibility of obtaining petroleum in quantity at Malbog could best be tested by drilling a series of wells along a west-northwest line across the crest of the fold. The structure appears to be favorable except that the anticline is rather sharp, and the presence of petroleum is demonstrated by the seepage, although there is no data as to the probable quantity. The vicinity of the Malbog seep is difficult of access; the narrow valley and the steep gradient of the creek, together with the elevation to be attained, would make transportation difficult and expensive.

ILLUSTRATIONS

TEXT FIGURES

FIG. 1. Geologic section across strike of beds at Toledo, Cebu; partly diagrammatic. *a*, coralline limestone; *b*, tuff and agglomerate; *c*, Miocene shales, sandstones, conglomerates, and limestones; *d*, basal igneous complex.

2. Geologic section across strike of beds along Malbog Creek, Alegria, Cebu. *a*, coralline limestone; *b*, volcanic tuff; *c*, Miocene shales and sandstones over limestone.

PUBLICATIONS FOR SALE BY THE BUREAU OF SCIENCE, MANILA, PHILIPPINE ISLANDS—Continued

BOTANY

A FLORA OF MANILA

By ELMER D. MERRILL

Order No. 419. Paper, 490 pages, $2.50, postpaid.

Practically a complete flora of the cultivated areas in the Philippines. Descriptions, with keys, of over 1,000 species, 590 genera, and 136 families, with native names, glossary of technical terms, etc.

THE COCONUT PALM IN THE PHILIPPINE ISLANDS

Order No. 37. Paper, 149 pages, 30 plates, $1, postpaid.

The reprint contains the following articles: On the Water Relations of the Coconut Palm (Cocos nucifera), The Coconut and its Relation to Coconut Oil, The Keeping Qualities of Coconut Oil and the Causes of its Rancidity, and The Principal Insects Attacking the Coconut Palm.

INDO-MALAYAN WOODS

By FRED W. FOXWORTHY

Order No. 411. Paper, 182 pages, 9 plates, $0.50, postpaid.

In Indo-Malayan Woods, Doctor Foxworthy has brought together a large amount of accurate information concerning trees yielding woods of economic value.

ZOOLOGY

A LIST OF THE MAMMALS OF THE PHILIPPINE ISLANDS, EXCLUSIVE OF THE CETACEA

By NED HOLLISTER

Order No. 418. Paper, 64 pages, $0.50, postpaid.

This is the only recent attempt to enumerate the mammals of the Philippine Islands. The distribution of each species is given, and the original descriptions are cited.

ZOOLOGY—Continued

A MANUAL OF PHILIPPINE BIRDS

By RICHARD C. MCGREGOR

Order No. 103. Paper, 2 parts, 769 pages, $4, postpaid.

A Manual of Philippine Birds contains in compact form descriptions of all the known species of Philippine birds. The usual keys and diagnoses of orders, families, and genera help the novice in identification.

A CHECK-LIST OF PHILIPPINE FISHES

By DAVID STARR JORDAN and ROBERT EARL RICHARDSON

Order No. 102. Paper, 78 pages, $0.75, postpaid.

This list will be found a convenient guide to the synonymy of Philippine ichthyology. The nomenclature is thoroughly revised, and the distribution of each species within the Philippine Islands is given.

MEDICINE

REPORT OF THE INTERNATIONAL PLAGUE CONFERENCE

Held at Mukden, April, 1911, under the auspices of the Chinese Government.

Edited by ERICH MARTINI, G. F. PETRIE, ARTHUR STANLEY, and RICHARD P. STRONG

483 pages, 18 plates (2 colored, 4 half-tones, 12 charts and maps)

Order No. 416. Paper, $2.50; cloth, $3.50; postpaid.

The proceedings of this international Conference and information gained therefrom, together with the results of certain bacteriological investigations, constitute the present report.

The Bureau of Science of the Government of the Philippine Islands has been appointed sole agent for the distribution of the printed proceedings of the International Plague Conference.

PRICES ARE IN UNITED STATES CURRENCY

Orders for these publications may be sent to the BUSINESS MANAGER, PHILIPPINE JOURNAL OF SCIENCE, BUREAU OF SCIENCE, MANILA, P. I., or to any of the agents listed below. Please give order number.

The Macmillan Company, 64–66 Fifth Avenue, New York, U. S. A.
Wm. Wesley & Son, 28 Essex Street, Strand, London, W. C., England.
Martinus Nijhoff, Lange Voorhout 9, The Hague, Holland.
Mayer & Müller, Prinz Louis Ferdinandstrasse 2, Berlin, N. W., Germany.
Kelly & Walsh, Ltd., 32 Raffles Place, Singapore, Straits Settlements.
A. M. & J. Ferguson, 19 Baillie Street, Colombo, Ceylon.
Thacker, Spink & Co., P. O. Box 54, Calcutta, India.

CONTENTS

Page.

PRATT, WALLACE E. The Location of Artesian Wells in the Philippine Islands from a Geologic Viewpoint........................ 231

PRATT, WALLACE E. Petroleum and Residual Bitumens in Leyte 241

PRATT, WALLACE E. On the Occurrence of Petroleum in the Province of Cebu.. 281

The "Philippine Journal of Science" is issued as follows:	U. S. currency.
Section A. Chemical and Geological Sciences and the Industries..	$2.00
Section B. Tropical Medicine	3.00
Section C. Botany	2.00
Section D. General Biology, Ethnology, and Anthropology (Section D began with Volume V)..	2.00
Entire Journal, Volume II, III, IV, or V	5.00
Entire Journal, beginning with Volume VI	7.00
Single numbers (except of Volume I)	.50
Each section is separately paged and indexed.	
Authors receive 100 copies of their papers free.	
Volume I, 1906 (not divided into sections) and supplement, sold only with a complete file of section A, B, or C........................	10.00
Supplement to Volume I (botany)	3.50
Volume I (without supplement), sold only with a complete file of section A, B, or C..	6.50
Single numbers of Volume I	.75

Publications sent in exchange for the Philippine Journal of Science should be addressed: Library, Bureau of Science, Manila, P. I.

Subscriptions may be sent to the Business Manager, Philippine Journal of Science, Bureau of Science, Manila, P. I., or to any of the agents listed below:

AGENTS

The Macmillan Company, 64-66 Fifth Avenue, New York City, U. S. A.
Wm. Wesley & Son, 28 Essex Street, Strand, London, W. C., England.
Martinus Nijhoff, Lange Voorhout 9, The Hague, Holland.
Mayer & Müller, Prinz Louis Ferdinandstrasse 2, Berlin, N. W., Germany.
Kelly & Walsh, Limited, 32 Raffles Place, Singapore, Straits Settlements.
A. M. & J. Ferguson, 19 Baillie Street, Colombo, Ceylon.
Thacker, Spink & Co., P. O. Box 54, Calcutta, India.

Entered at the post office at Manila, P. I., as second-class matter.